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ORIGINAL ARTICLES.

The Alston Block.

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Introduction.

THE area covered by this paper embraces the northern end of the Pennines—the uplands of Lower Carboniferous rocks centred about Alston, together with the low ground of the Tyne-Irthing gap to the north. It is bounded on the west by the Vale of Eden. The Pennine portion is separated structurally from the regions to the north and west by the Stublick and Pennine Faults respectively. The former trends E.N.E., it has a downthrow to the north and has resulted in the preservation of the string of Coal Measures outliers which form a connecting link between the Cumberland and Northumberland coalfields. The Pennine Fault, trending S.S.E., with a throw of several thousand feet to the west, brings the New Red rocks of the Vale of Eden against the Lower Carboniferous beds of the Pennine Escarpment. These two faults meet at right angles near Castle Carrock. To the south the Pennine Fault dies out near Stainmore, and another dislocation, the Dent Fault, trending S.S.W., develops, and eventually links up with the Craven Faults which have an E.S.E. trend. These four faults, as pointed out by Professor Kendall,[1] have the form of a reversed ʒ, and the region within this figure has become known generally as the Northumbrian Fault Block. Professor Marr has aptly termed the southern half of this area the "Rigid Block". The northern half of the Northumbrian Fault Block, which will be shown to possess many characters in common with the southern half, is here called the "Alston Block". Its limits are defined on three sides—by the Stublick Fault on the north, the Pennine Fault on the west, and by the Stainmore depression on the south. The last thus divides the

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[1] Kendall, Professor P. F., and H. E. Wroot, *The Geology of Yorkshire* (printed for authors), 1924, p. 234.

Northumbrian Fault Block into two, physiographically and structurally. The eastern boundary of the Alston Block is concealed beneath the Mesozoic rocks.

The present paper deals with the post-Carboniferous earth-movements of the Alston Block and the adjoining areas to the west and north, and with the relation of these to the intrusion of the Whin Sill. The Alston Block is recognized as an independent morphological unit in the tectonic evolution of the North of England. There is evidence that it existed in Devonian times, and it is shown here that it acted as a block during the deposition of the Carboniferous rocks, with a relatively unstable geosynclinal trough to the north. During the Hercynian compression it was depressed relatively to a geanticline, then formed on the site of the trough to the north. The strata outside the north-western margins of the Block were compressed into a group of crescentic folds, and on its margins a series of small scale folds were developed. The Whin Sill was then intruded, and, later, the compression found relief in the formation of a series of tear-faults. Still later, the Block as now defined was uplifted by post-New Red faults.

These conclusions, based on new evidence obtained during the re-survey of the Brampton Sheet, are at variance with some of those reached by Mr. Versey[1] in a recent paper. He has concluded that the Northumbrian Fault Block was uplifted during the Hercynian earth movements and that some of the faulting which accompanied this elevation antedated the intrusion of the Whin Sill.

The age of the faulting and its relation to the Whin Sill are of considerable importance to mining engineers in this district, where limestone coals are being exploited in faulted ground, and where the value of the coals has been destroyed locally by the proximity of sheets of the Sill.

THE DEPOSITION OF THE CARBONIFEROUS ROCKS.

The tectonics of the area are intimately connected with the deposition of the Carboniferous rocks which will be considered briefly. Two major geosynclinal troughs in which exceptionally thick Carboniferous sediments were formed, can be recognized in the North of England. The northern[2] lies between the southern Uplands and a line extending from the Isle of Man through the Lake District and the Alston Block to Durham. Deposition commenced in this trough with the Cementstones (C_1)[3] and this group together with the Fell Sandstones (C_2–S_1), a group of sandstones and thin limestones (S_1),[1] and a thick marine series (S_2) were deposited while much of the area south of the trough was land. With the possible exception of the highest beds of S_2 age none of these groups are represented in the north end of the Isle of man,[2] around the northern end of the Lake District,[3] on the Pennine Escarpment near Croglin,[4] or at Roddymoor [5] in Durham.

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[1] Versey, H. C., "Post-Carboniferous Movements in the Northumbrian Fault Block," *Proc. York. Geol. Soc.*, New Series, vol. xxi, 1927, pt. i, pp. 1–23.

[2] Trotter, F. M., and S. E. Hollingworth, "On the Upper Limestone Group and 'Millstone Grit' of North-East Cumberland," "Sum. of Prog." for 1926 (*Mem. Geol. Surv.*), 1927, pp. 103–5.

[3] Trotter, F. M., in "Sum. of Prog." for 1926 (*Mem. Geol. Surv.*), 1927, p. 51.

The Southern, Pendle or Bowland geosynclinal trough corresponds roughly with the so-called " Central Basin " of deposition, which includes the area south of the Craven Faults and extends to the Loughshinny district of Ireland. Thick sediments were formed in this trough commencing with the (?) *Zaphrentis* zone, continuing throughout Lower Carboniferous and Millstone Grit times and to some extent during the Coal Measure period. These troughs are separated by a belt of ground containing the Northumbrian Fault Block in the east, and the Lake District–Isle of Man area in the west. Several thousand feet of shallow water sediments were deposited in the subsiding troughs before the intervening areas were submerged in S_2–D_1 times. After the submergence of the Lake District–Isle of Man and the Alston Block regions the sediments formed on them differed from the corresponding beds in the troughs in being much thinner.

A third geosynclinal area lies between the Lake District and the Alston Block. Professor Garwood [6] has shown that in Ravenstonedale, and northwards as far as the River Eamont, thick sediments were accumulated from C_1 times onward. North of the Eamont the Lower Carboniferous is largely buried beneath New Red deposits but in the Brampton district where the Lower Carboniferous re-appears all the zones from C_1 onwards,[7] of Professor Garwood's type area have now been recognized. It is suggested, therefore, that these two areas were connected very early in the Lower Carboniferous period by a narrow gulf between the Lake District and the Alston Block. Thus a belt of thick sediments is probably continuous around the western and northern margins of the Alston Block.

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[1] The S_1 group has been called the Craighill Sandstones and the S_2 group the Birdoswald Limestone Group on the new geological maps.

[2] Smith, Dr. B., " On the Carboniferous Limestone Series of the Northern part of the Isle of Man," " Sum. of Prog." for 1926 (*Mem. Geol. Surv.*), 1927, p. 114.

[3] Earle, K. W., " The Lower Carboniferous Rocks of Cumberland," GEOL. MAG., 1922, p. 525.

[4] Hollingworth, S. E., in " Sum. of Prog." for 1925 (*Mem. Geol. Surv.*), 1926, p. 81, fig. 6 (Croglin Section).

[5] Lee, Dr. G. W., " On the Faunal Sequence of the Carboniferous Rocks met in the Roddymoor Boring, Co. Durham," " Sum. of Prog." for 1923 (*Mem. Geol. Surv.*), 1924, p. 146.

[6] Garwood, Professor E. J., " The Lower Carboniferous Succession in the North-West of England," *Quart. Journ. Geol. Soc.*, vol. lxviii, 1912, p. 484.

[7] Trotter, F. M., in " Sum. of Prog. " for 1926 (*Mem. Geol. Surv.*), 1927, p. 51.

Indications of the earlier existence of this Block may be mentioned here. Professor O. T. Jones[1] has suggested that the Lower Palaeozoic sediments beneath the Carboniferous area east of the Pennine Fault (i.e. the Alston Block of this paper) are comparatively thin and that they are underlain at no great depth by an Archean core. The pre-Carboniferous Middle Pennine Fault, with a downthrow to the west of 20,000 ft.[2] may be regarded as an expression of the western margin of the Alston Block in Devonian times.

It is therefore suggested that this Block acted as a structural unit from earliest Palaeozoic times to the end of the Carboniferous period. The reactions of the Block and the adjoining areas to later earth movements will be considered next.

HERCYNIAN EARTH MOVEMENTS.—FOLDS.

The Carboniferous sedimentation was terminated by uplift due to the oncoming of the Hercynian earth pressure from the south.

In the southern trough thick sediments were compressed into a well-known series of folds—the Bowland, Slaidburn, Clitheroe, and Lothersdale Anticlines, together with the Pennine Anticline farther south.

The resurvey of the Brampton Sheet has shown that the great northern trough also reacted to the Hercynian compression. Several anticlines have been recognized, the most important being the east–west Bewcastle Anticline, which is continuous at its western end with an anticline trending south-west. The southern limb of this curving anticline occupies the northern half of the Brampton area. As the St. Bees Shales unconformably transgress successive subdivisions in the denuded core[3] of this anticline its age is definitely pre-New Red. The denudation removed 7,000 feet of Lower Carboniferous rocks, as estimated in the resurvey of the Brampton Sheet, in addition to the whole of the Upper Carboniferous, estimated to be 3,000 feet thick by Peach and Horne[4] in the Canonbie Coalfield some 10 miles to the north-west.

A belt of highly dipping strata emerges from beneath the Trias $1\frac{3}{4}$ miles north of Farlam and can be traced in a curved line (see Fig. 1) for 3 miles to the north-east. This may be interpreted as a monoclinal fold on the southern limb of the Bewcastle anticline. A similar curved monoclinal fold has been observed on Denton Fell from Roachburn to Reaygarth. The major Bewcastle anticline and these two monoclinal folds are parallel to each other and change direction from north-north-east to almost east. They occur within each other in the order described and may be regarded as a group of crescentic folds of the same age and origin.

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[1] "The Foundation of the Pennines," *Manch. Geol. Assoc. Journ.*, i, 1927, p. 1.

[2] Marr, Dr. J. E., "The Geology of the Appleby District," *Proc. Geol. Assoc.*, vol. xx, 1907, p. 129.

[3] The old 1 in. map shows a faulted junction with the Trias.

[4] "The Canonbie Coalfield," *Trans. Roy. Soc. Edin.*, vol. xl, 1903, p. 835.

Another anticline, with an approximately E.–W. trend, crosses the South Tyne near Featherstone Castle; evidence of its age is lacking.

Other anticlines are probably associated with the tear-faults to be described later. The trend of their axes, as a group, is similar to that of the crescentic folds.

The lie of the strata on the Alston Block is in striking contrast to that in the adjoining area to the north of the Stublick Fault, for no folding of considerable magnitude is discernible on it. The similarity of this area with that of the Rigid Block of North-west Yorkshire is apparent. There, as here, the folded strata outside the block are in marked contrast with those upon it. Indeed the analogy may be carried still further, for the tear-faults of the Carnforth district,[1] outside the Rigid Block, may be compared with those developed in the strata adjoining the Alston Block (below). The comparatively unfolded sediments on both of these blocks are evidence of a rigid core, possibly Archean, which protected the Carboniferous cover during the Hercynian compression. There is, however, some evidence of compression on the Alston Block, for slight folding can be detected on it, and in the crests and troughs of these folds the Whin Sill increases in thickness (p. 445). It would appear, therefore, that the intrusion of the Sill was contemporaneous with, or later than, the compression which produced the folds.

Still further evidence of compression is apparent. A group of small acute folds of a different order and arrangement from those described above fringe the western and north-western marginal areas of the Alston Block (see Fig. 1). They are restricted to resistant beds, particularly limestones, and die out vertically within the individual beds. The axis of these folds progressively change from S. 30° E.–N. 30° W. near Croglin to S.–N. near Castle Carrock and to S. 15° W.–N. 15° E. near Tindale Tarn, thus maintaining a general parallelism with the margin of the Block and with the direction of the larger crescentic folds.

TEAR-FAULTS.

A series of faults fringe the north-west margin of the Block in the sediments of the trough to the north of it. As a group they change in direction from W.S.W.–E.N.E. in the south-west to N.W.–S.E. in the north-east. They have the following characteristics in common.

(1) They are dip faults.

(2) Their throw is southward, so that as a group they would have the effect of depressing the Block in pre-Triassic times, relatively to the area north of it.

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[1] Marr, Dr. J. E., *The Geology of the Lake District*, Camb. Univ. Press, 1916, p. 119.

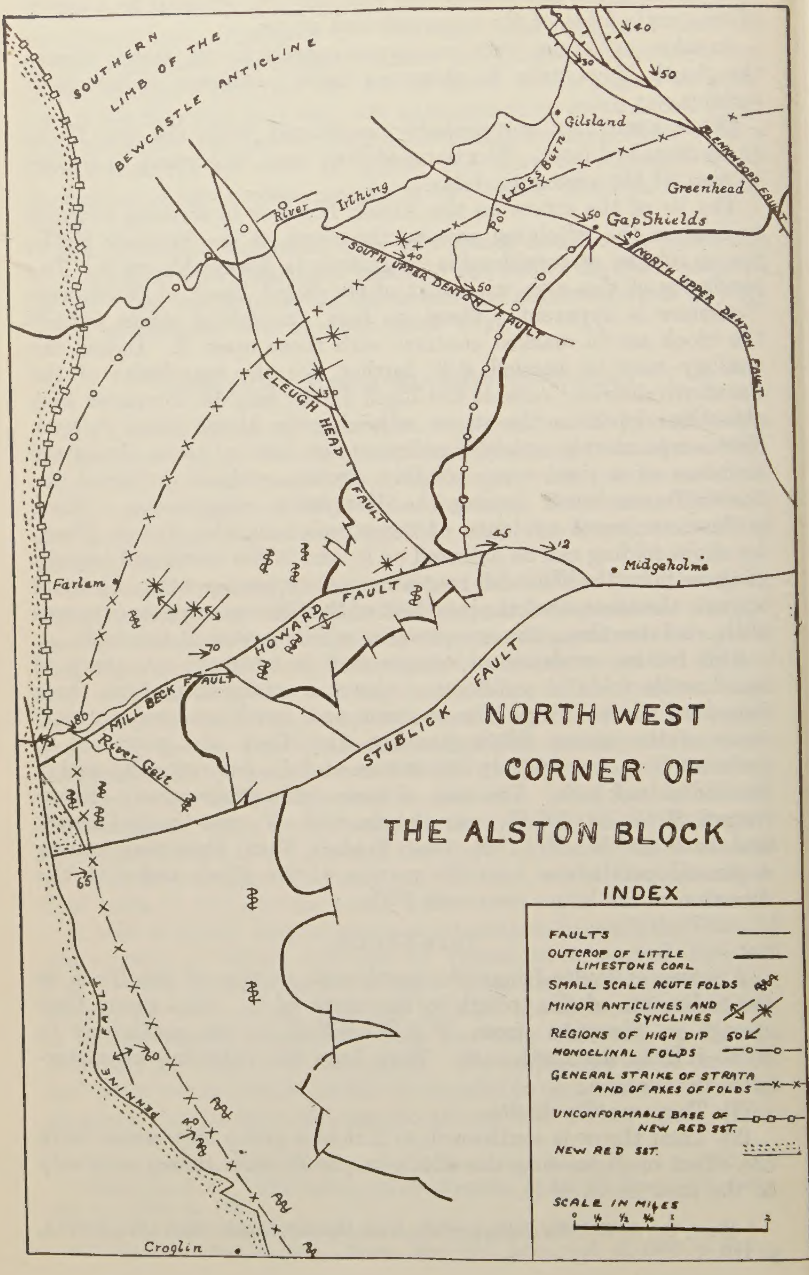

FIG. 1.—Structural map of the North-west Corner of the Alston Block and adjoining areas.

(3) The strata on the north side of the faults are folded into a series of anticlines and synclines with axes making high angles with the faults (see Fig. 1), the beds as a whole having a general dip to the south-east. These folds gradually die out when traced north-westwards from the north side of one fault to the south side of the next. Frequently high dips to the south-east alternating with comparatively low dips in the same direction are found on the northern sides of the faults. These are interpreted as asymmetric folds in an area of general south-easterly dip off the southern limb of the Bewcastle anticline.

These facts indicate a horizontal compressional movement eastward on the northern side of each fault. The faults must therefore be considered to be tear-faults. They will be briefly described in order from south to north.

The *Mill Beck Fault* (see Fig. 1) shows to best advantage the striking difference in dip on the two sides of the fault. On the north side a strong anticlinal fold is developed immediately adjacent to the Trias overlap in the River Gelt and the dip maintains high angles of from 45° to 90° in the River Gelt and to the north-east. On the south side horizontal beds crop out. The continuation of this fault in an easterly direction as the Howard Fault is reversed in throw, but high dips are developed on the north side near Cardiff, and again at Roachburn Colliery. The reversal of the throw of the fault in this area is considered to be the result of a second movement associated with the elevation of the Northumbrian Fault Block in post-Triassic times (see p. 448). The steepened dips and the folding in the Gelt are in marked contrast with the gentle dip and the absence of folding in the Trias which here unconformably overlies the Carboniferous. Similarly 1¾ miles north of Farlam highly inclined Carboniferous strata dipping E.S.E. are overlain by the New Red Sandstone series dipping gently to the west. There is thus definite evidence that these movements are earlier than the deposition of the New Red Rocks.

East of Farlam, in the area between the Mill Beck and Clough Head Faults, several folds can be recognized.

The *Clough Head Fault* is probably a tear-fault, for it has the trend and throw common to the tear-fault system, and has an associated fold on its north side near Highfield.

The *South Upper Denton Fault* is well exposed in a small stream near Chapel Burn, where high dips are associated with a fold on the north side. High dips are again observable in Poltross Burn, where the fault has a maximum " vertical " throw of 100 feet.

Across the *North Upper Denton Fault* near Gapshields high dips exist at both sides of the fault as it is here crossing the pre-existing inner crescentic fold. The throw decreases south-eastward from 460 ft. near Gapshields, where the dip is 45° to 180 feet in the Coal Measures at West Coanwood, where the dips are about 15°.

A narrow fan-shaped group of five faults well exposed in the

Irthing north of Gilsland converges to the south-east to form the *Blenkinsopp Boundary Fault.* In Blenkinsopp Colliery the fault has a throw of 250 feet down south-west, but this decreases in a south-easterly direction to 100 feet across the South Tyne. High dips occur immediately to the north of this fan-shaped group of faults near Barn House. In the Thirlwall Colliery the dip has been proved to decrease rapidly when traced north-east along the strike away from this fault. The Whin Sill is definitely at the same geological horizon—that of the Five Yard Limestone—on each side of this fault.

THE WHIN SILL.

Historical.—Phillips held the view that this igneous sheet was interbedded with the strata and so occurred at a constant horizon. Tate [1] later proved its intrusive character, and was supported by Topley and Lebour,[2] who considered, on negative evidence, that it was intruded into the Carboniferous before the deposition of the Permian. Its petrography has been described by Teall.[3]

Some positive evidence of the age of the Whin Sill has been obtained recently by Dr. Holmes [4] who has found a pebble of it in the Upper Brockram near Appleby. It is, therefore, definitely older than that deposit. As the Whin has not been recorded from the Lower Brockram Professor Gilligan [5] considers that its date may be restricted to the interval between the formation of the Lower and Upper Brockrams.[6]

Mr. Versey places the date of the intrusion of the Whin Sill in the interval between two periods of faulting considered by him to be of Hercynian age.

Phacolitic Character.—The term phacolite has been used by Dr. Harker for lenticular sills which are the result of intrusion into folded strata. Similar lenticular forms would result if folding and faulting took place simultaneously. In general, pressure will tend to produce folding, and if a sill were intruded contemporaneously, the liquid magma would accumulate as a thickened sill in areas of relative relief from pressure (the incipient crests and troughs) and so develop a lenticular cross section, although the compression might not be sufficiently intense to produce appreciable folding. The term phacolite is used here to include such lenticular forms, where no direct evidence of folding is seen.

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[1] Tate, G., "The Basaltic Rocks of Northumberland," *Proc. Ber. Nat. Club*, vol. vi, 1871, pp. 197–217.

[2] Topley, W., and G. A. Lebour, "On the Intrusive character of the Whin Sill of Northumberland," *Quart. Journ. Geol. Soc.*, vol. xxxiii, 1877, pp. 406–22.

[3] "The Chemical and Microscopical Characters of the Whin Sill," *Quart. Journ. Geol. Soc.*, vol. xl, 1884, pp. 640–57.

[4] Gilligan, Professor A., *The Geology of the Appleby District*, Whitehead and Son, Appleby, 1926, p. 21.

[5] Op. jam. cit., p. 21.

[6] On account of the excessive rarity of the Whin pebbles in any of the Brockrams, this conclusion does not appear to be warranted.

The Whin Sill usually outcrops as a continuous sheet to the north of the Alston Block and along its western margin, but within a limited area of the Brampton Sheet it has been proved to occur as a series of discontinuous lenticular outcrops. It is possible that these lenticular sills may be true laccolites, but no feeders have been proved. A number of dykes of similar characters to the Whin Sill have, however, been mapped, and these may have acted as feeders.

The phacolitic character of the Whin Sill in this area is considered to be a consequence of localized pressure on the north-west corner of the Alston Block during the intrusion of the Sill acting in conjunction with the general northward directed Hercynian pressures. Evidence of phacolitic thickening produced by the latter has been brought forward by Mr. Versey in the case of the Whin Sill of the Teesdale anticline.

A fine example of a phacolite is seen in Black Burn, south-east of Midgeholme. The Sill, 140 feet thick in the burn, thins rapidly along the hillside to the east and disappears completely within a distance of ¼ mile. Lenticular sills or phacolites have also been mapped in the Coal Measures near Midgeholme, and in the South Tyne drainage at Tows Bank, and Thinhope Burn. Their petrography will be discussed in the forthcoming memoir.

Variation in Horizon.—In the north-western part of the Alston Block the Whin Sill makes great changes in horizon, the essentially localized character of which is brought out by a consideration of its geological horizon in the areas to the south and north-east.

On the Pennine Escarpment at High Cup Nick, the Whin Sill lies below the Tyne Bottom Limestone; from this point it gradually rises to the horizon of the Scar Limestone when traced northwards to Croglin, where it dies out, a change of only 100–150 feet in 20 miles. From Croglin northwards for a distance of 4 miles there is a rapid change upward in horizon; thus when it reappears it is above the Great Limestone, a change of horizon of 450 feet, and farther north on the south side of the Stublick Fault it lies some 1,050 feet above the Tyne Bottom Limestone. To the north of this fault it is absent for a distance of 2½ miles, and when it reappears it lies beneath the Four Fathom Limestone—500 feet above the Tyne Bottom Limestone. Immediately north of this it is in the Coal Measures—2,600 feet above the Tyne Bottom Limestone; farther north it occurs below the Five Yard Limestone—some 300 feet above the Tyne Bottom. From this point north-eastward the region of rapid change of horizon is left and for a distance of 20 miles it outcrops within 100 feet of the Five Yard Limestone. This remarkable variation of horizon which takes place as the north-west corner of the Block is approached is illustrated in Fig. 2, in which isohypses of the position of the Whin above the Tyne Bottom as a base line are drawn.

The figure also shows the general westward rise in horizon of the Whin toward the escarpment throughout the northern half of the

Alston Block. The following example illustrates this, and also shows the progressive thinning of the Sill on approaching the western margin of the Block. In Rotherhope Fell Mine the Whin Sill is 192 feet thick, and occurs below the Tyne Bottom Limestone ; it is 80 feet thick (base not seen) in Gilderdale, where it is some 70 feet above the same limestone, and in Croglin Water, where it is divided by 6 feet of strata into two beds each 20 feet thick, it immediately underlies the Scar Limestone. Still farther west in a quarry north-west of Croglin the Sill thins from a bed 10 feet thick to thin strings, totalling less than 2 feet thick, within the Scar Limestone. In this quarry where the Whin is dying out the most easterly acute folds characteristic of the western margin of the Alston Block are first developed.

The close connection of the acute folds with the Whin Sill in the north-west corner of the Alston Block is significant, for no such folds have been found within the area in which the whin occurs. Indeed, a curved line can be drawn separating the known occurrences of Whin Sill from the marginal area of acute folds. One may conclude that the conditions of pressure over the Alston Block during the intrusion of the Whin Sill were such that the liquid magma found relief by lateral extension in sill form. The presence of strong compression and its associated folding on the western margin of the block caused the sill to thin westward, and probably proved, in the northern part of the Alston Block at least, an effective barrier to further extension in that direction. The folding and faulting around the north-west part of the block indicate that this corner was subjected to particularly intense earth pressure. This localization of stress is intimately connected with the local abnormalities in the behaviour of the Whin Sill, for it is here that this magma developed its markedly discontinuous phacolitic character, and found relief from the stress by great upward changes of horizon.

THE RELATION OF THE WHIN SILL TO FAULTING AND ITS ECONOMIC ASPECTS.

The abnormal characteristics of the Whin Sill are displayed in an area where numerous limestone coals are, and have been worked, viz. the coals below the Oakwood, Little, Four Fathom, Three Yard, Five Yard, and Scar Limestones. The intrusion has influenced the exploitation of these coals, and a knowledge of its behaviour is of the utmost importance to mining engineers. This can be better appreciated by a study of the following examples.

The Little Limestone Coal near Tows Bank is overlain at a distance of 30 feet by a Whin Sill 20 feet thick which has completely coked the coal, and driven off all the volatile constituents.

The influence of the Whin is again seen by comparing the analyses of the Little Limestone Coal at Gair's Colliery and Venture Pit.

	Gair's Colliery.	Venture Pit.
	%	%
Fixed carbon . .	79·6	63·83
Volatile matter .	16·6	34·3
Ash . . .	3·8	1·87

At Gair's Colliery where the whin is 350 feet above the Little Limestone Coal, the analysis shows a striking loss of volatile constituents compared with that at Venture Pit, where there is no Sill within at least 1,000 feet of the coal. This example shows that the Whin Sill can affect coal where it lies as much as 350 feet above the seam. The relation of the Whin Sill to faulting is also economically important, for if the whin is intruded *after* faulting it may change its horizon in crossing a fault and so lie much nearer to a particular coal on one side of the fault than the other.

Mr. Versey gives three examples in the Brampton district of whin occurring at a different horizon on opposite sides of faults. He interprets this as the result of faulting of the strata *prior* to the intrusion of the sill. Our observations, however, do not support this interpretation. We propose therefore to discuss briefly the field evidence in each of these cases.

1. The original 1 inch geological map of the Brampton district (Sheet 18) shows a change of horizon of the Whin Sill on opposite sides of the North Upper Denton Fault, which has been accepted by Mr. Versey, but the identification of the individual limestone on the south side of the fault during the resurvey of the sheet has shown that there is no such change of horizon. As in the case of the Blenkinsopp Fault (see p. 442), it lies below the Five Yard Limestone on both sides of the fault.

2. The whin occurs above the Scar Limestone ½ mile north of the South Upper Denton Fault. At the fault it is obscured by drift. Immediately south of it a section is seen in Poltross Burn. Here the Scar and the underlying Cockleshell and Single Post Limestones are exposed, but no trace of whin is seen. The higher limestones are under drift. The whin, therefore, does not change its horizon in crossing this fault to below the Scar Limestone—the position assigned to it in Mr. Versey's sketch.[1]

3. The resurvey has shown that the Stublick Fault has a downthrow to the north in the Trias as well as in the Carboniferous (see Fig. 1). It is, therefore, of post-New Red age, but earlier movement along it is by no means improbable. The whin occurs to the south of the fault, but no whin is seen for 2½ miles to the north of it, although the strata from 600 feet below the Tyne Bottom to 500 feet above the Little Limestone are well exposed. Mr. Versey has figured the whin as being intruded after faulting, occurring above the Little Limestone on the south side of the Fault, and below the Four Fathom on the north side. and calculates a pre-whin throw

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[1] Versey, H. C., op. cit., p. 10.

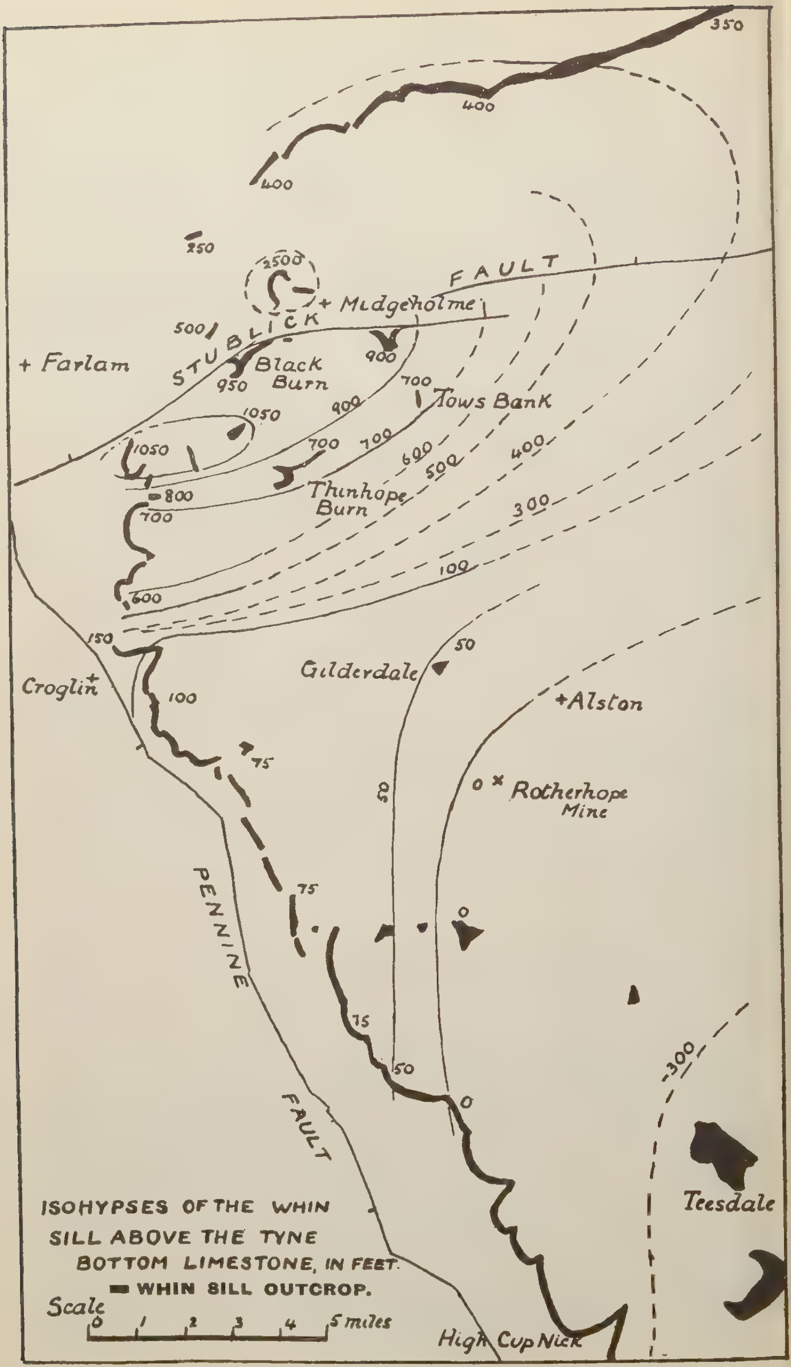
350
400
400
250
2500
FAULT
+ Midgeholme
STUBLICK
500
+ Farlam
Black Burn
950
900
700
Tows Bank
900
1050
1050
700
700
600
500
400
800
700
Thinhope Burn
300
100
600
150
Croglin +
Gilderdale
50
100
+ Alston
75
50
o × Rotherhope Mine
PENNINE
75
0
FAULT
75
50
0
300
Teesdale
ISOHYPSES OF THE WHIN SILL ABOVE THE TYNE BOTTOM LIMESTONE, IN FEET.
WHIN SILL OUTCROP.
Scale
0 1 2 3 4 5 miles
High Cup Nick

FIG. 2.

of 250 feet, as the whin is actually 300 feet above the Little Limestone on the south side his explanation necessitates a downthrow *to the south* of 600 feet His inference that this faulting represents the initiation of the uplift of the Block by a downthrow *to the north* is therefore clearly invalid.

To sum up, we have found no evidence to support the view that faulting took place in this area before the intrusion of the Whin Sill, hence there is no reason to expect that it will be nearer a coal seam on one side of a fault than on the other. It must be remembered, however, that at the north-west corner of the Alston Block the Whin varies rapidly in horizon independently of faulting.

AGE OF THE WHIN SILL.

At least two of the Hercynian tear-faults have been proved to displace the whin (p. 440); the intrusion, therefore, is earlier than the faulting. There can be little doubt that the Whin Sill was intruded later than, or contemporaneously with, the pressure which produced the large crescentic folds outside the Alston Block and the small acute folds around its north-western corner. Hence it must have been intruded in the interval between the initiation of the folding and the later faulting of Hercynian age.

HERCYNIAN MOVEMENTS (SUMMARY).

The following brief explanation of the observed facts due to Hercynian movements is suggested.

In the general northward movement of the earth's crust the comparatively rigid masses forming the underlying cores of the Alston Block and the Lake District–Isle of Man mass are considered to have moved northwards at a greater rate than the Southern Uplands Horst of Scotland because they were nearer the southern source of compression. As a consequence the Bewcastle–Mid-Northumberland geosynclinal trough, lying in advance of the more rigid Alston Block, was folded along approximately east–west lines. The Lake District encountered greater resistance than the Alston Block in the northward movement as it was nearer to the Southern Uplands. Its resultant direction of movement then became east of north, a direction which caused it to converge relatively towards the Alston Block and compress the intervening strata against it, and thus form the acute folds. This compression eventually produced a movement of the strata north-eastward and eastward around the north-west corner of the Block. The strata adjacent to the Block encountered greater resistance than that farther to the north and so moved more slowly. This differential movement ultimately produced the series of successive tear-faults by relative movement eastward on the northern sides of the faults. A close analogy may be drawn between the movement producing these tear-faults and that forming the marginal crevasses in a glacier. The trend of the fractures in both cases is backward from the margins towards the source of movement at an angle of 45° to the lateral margin.

The authors wish to express their thanks to Dr. Bernard Smith for helpful criticism of this paper. He has suggested that the system of faults and folds here described is such as would be expected from a clockwise rotation of the Alston Block in its travel northwards. It is possible that the general northerly and local north-easterly forces acting on the Block would produce such a rotation, but the final explanation of these movements must await further detailed work in the tectonics of a much larger area.

THE ALSTON BLOCK IN PERMO-TRIASSIC TIMES.

In the core of the Bewcastle Anticline, near Kirkcambeck, the basal breccia of the St. Bees Shales rests on the upper beds of the cementstones. This shows that enormous denudation had taken place before the deposition of the Trias, for the Coal Measures ? 3,000 feet thick, the "Millstone Grit" 280 feet, the Upper Limestone Group 1,500 feet, the Middle Limestone Group 1,250 feet, the Lower Limestone Group 850 feet, Birdoswald Limestone Group 1,500 feet, Craighill Sandstone Group 800 feet, Fell Sandstones 1,000 feet, amounting in all to 10,000 feet, of strata, had been eroded. On the other hand 500 feet of Coal Measures at Midgeholme and the greater part of the Upper Limestone Group on the Alston Block are even now preserved to the south of the anticline. This indicates that the northern end of the Block was depressed relatively to the Bewcastle Anticline in pre-Triassic times. The throw of the tear-faults yields confirmatory evidence of this depression (p. 439). Recently Mr. Turner[1] has brought forward evidence that the southern part of the Alston Block in the Westmorland Pennines was depressed in pre-Permian times relatively to the Eden Valley on the west. It is reasonable to conclude that the whole of the Alston Block was depressed as the result of the Hercynian movements.

This view necessitates a reconsideration of the origin of the Permian Brockram of the Vale of Eden. These have been interpreted by Professor Kendall, whose view is generally accepted, as torrential deposits derived from high ground on the east, which towered above the Vale as a fault scarp, and was renewed by uplift during the formation of the Penrith Sandstone. Mr. Turner has given reasons to suppose that the Vale of Eden was elevated relatively to the area to the east. He has questioned the eastern origin of the Brockram and suggests their derivation from high ground on the site of the present Lake District. While not entirely accepting his view of the source of the Brockram, we are in agreement with the conclusion that the Brockram was not derived from the east. Mr. Turner has shown that the Brockrams do not become coarser or more angular towards the Pennine Escarpment. On the other hand they thin out when traced from south to north. Additional evidence is available to support his view. North of Armathwaite lenticular beds of conglomerate in the Penrith Sandstone are made up almost entirely of limestone pebbles. These cannot have been derived from the Escarpment, for in this district the Carboniferous Limestone Series shows a typical Yoredale facies in which sandstone beds are as thick as the limestones. Indeed, this deposit is in striking contrast with the local basal conglomerates of the New Red which have been derived from areas of Yoredale facies. In these sandstones predominate, although limestone pebbles are present. The limestone pebble conglomerate can only have been derived from massive limestone country which lay to the south.

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[1] Turner, J. S., "The Lower Carboniferous Succession in Westmorland Pennines and the Relations of the Pennine and Dent Faults," *Proc. Geol. Assoc.*, vol. xxxviii, 1927, p. 371.

It has been shown that the Bewcastle–Mid-Northumberland trough was elevated into an anticline by Hercynian earth movements, the southern or Bowland trough was also folded. An east–west anticline runs from Middleton Dyas in the east through the Howgill Fells to south of St. Bees Head. This anticline was formed as a result of the Hercynian earth movements, for in the east the Magnesian Limestone rests successively on the Coal Measures, Millstone Grit, and Carboniferous Limestone when traced from north to south. In the Vale of Eden Mr. Turner has shown that the Penrith Sandstone rests on successively lower divisions of the Carboniferous Limestone when traced from north to south. Similarly in West Cumberland the Brockram overlaps the Carboniferous on to the Older Palaeozoics from north to south.

We prefer to regard this uplifted anticlinal axis as the source of the Brockrams of the Vale of Eden, particularly as the anticline passes through the thick limestones in the Ravenstonedale trough of Carboniferous sedimentation. South of the anticline, the conglomerates of the Ingleton Permian outlier may be considered to support this view, for Professor Kendall[1] has shown that they were derived from the north.

It may be noted here that the Middleton Dyas and Bewcastle Anticlines have a pronounced pre-New Red pitch to the east, for the oldest rocks of these anticlines appear in the cores at their western ends, where they are unconformably overlain by the New Red. The conception of the Alston Block depressed between two easterly pitching anticlines on its northern and southern margins has a necessary corollary, viz. that the Pennine axis, which separated the Yorkshire and Lancashire Coalfields in the south, did not extend to the Alston Block in Permo-Triassic times.

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[1] Kendall, Professor P. F., "The Geology of the Districts around Settle and Harrogate," *Proc. Geol. Assoc.*, vol. xxvii, 1911, pp. 46–7.

POST-TRIASSIC HISTORY OF THE BLOCK.

It has been shown that the Block was not uplifted by the Hercynian earth-movements or during the deposition of the New Red rocks.

The Stublick Fault, forming the present northern boundary of the Block, has a downthrow to the north in the Trias (see Fig. 1).

Similarly the Tyne Bottom (or Tynemouth) Fault, which may be regarded as an expression of its northern margin in the east, throws down the Magnesian Limestone to the north. The Pennine Fault also affects the Trias. The available evidence then, is wholly in favour of the post-Triassic age of the elevation of the Block.

The later Mesozoic appears to have been a period of quiescence and the uplift of the Alston Block—the last great stage in its evolution—probably formed part of the widespread crustal movements of earlier Tertiary times.

The Petrography of the Triassic Sandstone of North-East Ireland.

By DORIS L. REYNOLDS, M.Sc.

I. INTRODUCTION AND LOCALITIES VISITED.
II. MINERALOGY.
    (a) Method of examination.
    (b) Description of the minerals.
    (c) Distribution of the minerals.
III. DESCRIPTION OF THE CONGLOMERATE AND PEBBLE BEDS.
IV. THE SOURCE OF THE PEBBLES.
V. HEAVY MINERALS PRESENT IN THE PEBBLES.
VI. HEAVY MINERALS IN NEIGHBOURING OLDER FORMATIONS.
VII. THE SOURCE OF THE HEAVY MINERALS IN THE TRIASSIC SANDSTONE.
VIII. THE GEOGRAPHY OF NORTH-EAST IRELAND IN TRIASSIC SANDSTONE TIMES AND THE MODE OF ACCUMULATION OF THE MATERIAL.
IX. THE CORRELATION OF THE SANDSTONE.

I. INTRODUCTION.

BETWEEN the years 1869–83 the Triassic sandstone of North-East Ireland was examined and mapped by the Geological Survey under the direction of Hull. The rocks were correlated with those of similar age in Lancashire and Cheshire, the lithological characters described and the exposures noted. Later the Belfast district was resurveyed under the direction of Lamplugh, who suggested, in the Memoir published in 1904, that the Triassic sandstone should be correlated with the St. Bees sandstone rather than with that of Lancashire and Cheshire. Attention was also drawn to the probable incorrect mapping of the Trias near Belfast.

No attempt has yet been made to tackle the problem of the origin of the Trias in Ireland and the present investigation was undertaken in the hope of attaining something in that direction. It is concerned mainly with the mineralogical constitution of the Triassic sandstone and includes additional information concerning the conglomerate beds.

The rocks of Triassic age in Ireland are entirely restricted to the

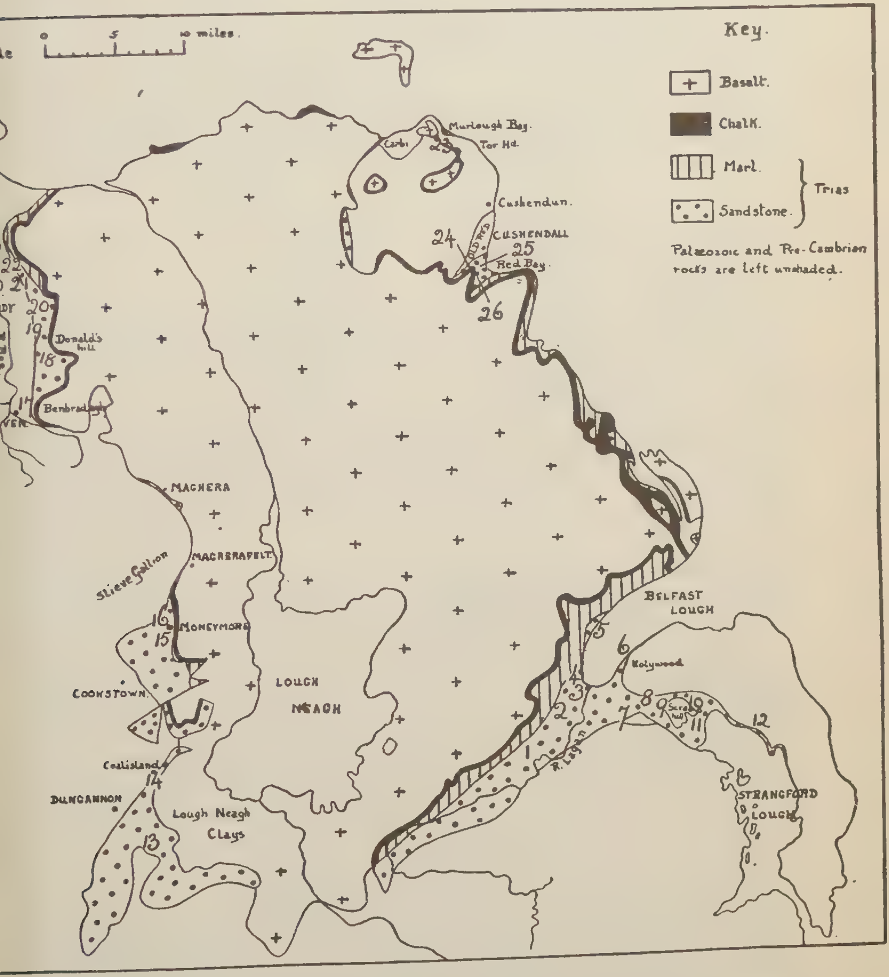

FIG. 1.—Sketch-map of N.E. Ireland showing the distribution of the Triassic sandstone. The numbers refer to the localities from which material has been collected. (See Table I.)

north-eastern counties, where they emerge in an almost continuous outcrop at the base of the Chalk and basalt escarpment of the Antrim plateau, in Antrim, Down, Armagh, Tyrone, and Londonderry.

A small faulted outlier occurs, farther south, near Kingscourt, on the borders of the counties of Cavan and Meath.

Although the area over which Triassic sandstone is known to occur is of considerable extent, the number of exposures is exceedingly small. This is due to the general association of these soft rocks with the larger valleys and depressions of the region and the thick covering of drift which everywhere conceals their floors. One has in consequence to rely on artificial excavations, stream sections, and occasional coast exposures. In many cases the sections noted by the Survey are no longer visible, the old quarries being frequently filled with water, and the small stream sections grassed over.

Localities visited.

Samples of sandstone have been collected from the following localities :—

Co. Antrim.—Belfast District : Falls Road, Skegoniel, Fortwilliam Park ; White Abbey (north of Belfast Lough) ; Milltown (near Dunmurry). Cushendall district : Glenariff, Red Bay, Ballyeamon River, Murlough Bay.

Co. Down.—Marino (coast near Holywood) ; Dundonald : stream dividing the townlands of Ballybeen and Ballyhaywood, stream west of Dunlady House. Red stone quarry between Dundonald and Newtownards. Scrabo Hill. Ards Peninsula : Ballyhaft Cottage.

Co. Tyrone.—Red Ford (near Dungannon). Torrent River, Coalisland.

Co. Londonderry.—Moneymore : stream near Maple Lodge, Boherboy Cottage. Benbradagh (near Dungiven). Donald's Hill. In the following streams which flow westward into the Roe :—

1. The stream east of Drumagosker.
2. The stream flowing from Kready mountain to Drummond bridge.
3. Curly River.
4. The stream which flows under Artikelly Bridge (near Limavady).

Co. Cavan.—Enniskeen River (near Kingscourt).

II. MINERALOGY.

A. *Method of examination.*

The sandstone was crushed, passed through sieves, boiled in 30% HCl., washed, dried, and separated by means of bromoform. It is usually highly ferruginous, so that it was necessary to boil it for several hours in HCl. Since this would cause the complete disappearance of some minerals, e.g. apatite, an additional separation, without preliminary boiling in HCl., was made in the case of the paler sandstones. A quantity averaging about 60 gms. was separated at a time, larger amounts being panned, previous to separation in bromoform in the case of samples deficient in heavy minerals. This was found advisable in order to verify the presence or absence of minerals that are only represented by one or two grains in each separation. A bar magnet and electromagnet were sometimes used for further separations.

Several specimens were thus examined from each locality, to ensure that an average sample had been taken and to note any variation at different horizons.

B. *Description of Minerals.*

The following is a list ot the minerals identified :—

- (1) Cubic—
  - Garnet.
  - Magnetite.
- (2) Tetragonal—
  - Anatase.
  - Rutile.
  - Zircon.
- (3) Hexagonal—
  - Apatite.
  - Calcite.
  - Hematite.
  - Ilmenite.
  - Quartz.
  - Tourmaline.
- (4) Orthorhombic—
  - Brookite.
  - Staurolite.
- (5) Monoclinic—
  - Biotite.
  - Chlorite.
  - Hornblende.
  - Muscovite.
  - Orthoclase.
- (6) Triclinic—
  - Microcline.
  - Plagioclase.

In addition an authigenic mineral was found in the sandstone from Benbradagh.

Garnet.—This mineral is most abundant in the coarser beds. It occurs, for example, almost to the exclusion of the other minerals in the coarse sandstones near Dundonald railway station, where the grains average ·15 mm. in diameter, some being ·5 mm. Under the microscope the smaller grains are seen to be colourless, the larger ones, however, vary from pale to deep salmon pink. They are angular and commonly diamond shaped, both angularity and shape being due to the excellent development of the dodecahedral cleavage. In appearance they recall those figured by Bosworth (1)[1] from the Coal-Measure sandstones of Scotland.

The garnets frequently show inclusions, which occasionally are so crowded that the garnet does not appear isotropic. The inclusions are small stumpy prismatic crystals with well-marked boundaries. Their refractive index is lower than that of garnet and the double refraction is low and extinction straight. They are probably apatite.

Magnetite, recognizable by its magnetic properties and bluish-black colour in incident light, is never abundant. It occurs as rounded or ragged grains.

Anatase occurs as aggregates of small crystals growing from grains of leucoxene, and more rarely as isolated rectangular crystals of tabular habit averaging about ·05 mm. This form results from the combination of a broad basal plane and exceedingly narrow pyramid faces. The crystals vary from colourless to pale yellow and are usually clear. The crystal angles are always perfectly sharp, which would seem to indicate that the whole of the anatase was derived from leucoxene after the deposition of the sandstone.

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[1] Figures in parentheses refer to Bibliography at the end of the article.

Rutile was observed as ovoid grains averaging ·1 mm. in length and less frequently as worn prismatic crystals, often striated parallel to the vertical axis and showing the following forms :—100, 110, 111. In the sandstone east of Drumagosker, near Limavady, grains as large as ·37 mm. by ·2 mm. occur. Geniculate and polysynthetic twins are rarely present. The colour varies from golden-yellow to deep reddish-brown, the former predominating: pleochroism is strongly marked, in yellow crystals O pale yellow, E deep amber, and in brown crystals O reddish-brown, E dark red.

Zircon is most abundant in the finer sandstones, where it forms the predominant heavy mineral. It occurs as oval grains and also as prismatic crystals, the two types occurring together in almost every sample. The crystals and grains vary from ·075 mm. to ·37 mm. in length.

In the sandstone of Scrabo Hill the zircons are perfectly formed, fairly uniform in size with an average length ·075 mm. They show the following forms recorded in order of frequency :—

100 and 110 terminated by 111.
100 and 110 terminated by 111 and 311.
100 terminated by 111.
110 terminated by 111 and 001.

Zoning is not uncommon in the larger grains. Inclusions are numerous and in the case of the zoned crystals are zonally arranged. They consist of zircon prisms, prisms and occasional needles of rutile, slender prisms of apatite and long tubular glass inclusions. The zircons are generally clear, but some are cloudy, possibly as the result of decomposition, whilst others are brownish. Purple zircons, oval in shape and sometimes of considerable size, have been found in samples of sandstone from Cos. Londonderry, Antrim, and Cavan. These evidently belong to the type described by Mackie (2) as originating in the Lewisian gneiss.

Apatite is probably characteristically present, though its occurrence could only be ascertained in the pale coloured sandstones which it was possible to examine without a preliminary boiling in HCl. In these it forms one of the most abundant of the heavy minerals, occurring in colourless well-rounded grains, often perfectly spherical and occasionally exhibiting the imperfect cross cleavage. The grains vary from ·075 mm. to ·1 mm. in diameter.

Calcite is present as a cementing material and also occurs filling cavities in the sandstone near Limavady and in veins at Scrabo Hill, in both localities exhibiting the scalenohedral form.

Hematite.—In addition to its occurrence as a cementing material, hematite is frequently present as large ragged plates.

Ilmenite was observed as rounded and ragged grains, forming often one of the most abundant of the heavy minerals. It shows signs of alteration to leucoxene, which not infrequently has entirely replaced it.

Leucoxene as an alteration product of ilmenite is abundant in rounded opaque grains, which are white, yellow, or brown in colour. Anatase can frequently be observed growing from the surface of the grains.

Quartz occurs as rounded, sub-rounded and angular grains, the larger ones only showing complete rounding.

Strain shadows were very frequently noticed and a large number of the fragments are composite, consisting of interlocking grains which sometimes show an elongation in one direction. These have evidently been derived from metamorphic rocks.

The researches of Mackie (3) on the quartz of the Scottish granites, gneisses, and schists have shown that the type of rock from which quartz grains have been derived can be determined from the nature of the inclusions. An examination of the inclusions in the quartz grains of the Triassic sandstone of this area shows the following types to be present :—

1. Regular : zircon, tourmaline, rutile, biotite, and possibly apatite.
2. Acicular : needles of rutile.
3. Irregular : glass (occasionally with enclosed bubbles), and very fine black inclusions, not determined.

Of these the regular type of inclusion is the most frequent.

Dr. Mackie says that " It may be stated as a fairly general law that acicular and irregular inclusions pre-eminently abound in the quartz of granite ; that the regular group is to be found in various proportions, but always in relatively large numbers in the quartz of gneiss and the younger schistose rocks."

Tourmaline.—Its most common variety is of a deep brown colour and occurs as almost spherical grains, less frequently as prismatic crystals with rhombohedral and rounded terminations. Occasional striations parallel to the c axis were observed, and strong pleochroism is shown : O dark brown, E pale yellow. Blue tourmaline, exhibiting less strongly marked pleochroism, is also present in small amount. It occurs as splinters and small subangular grains. Pinkish tourmalines are frequently present, occurring as prisms with rounded terminations ; they are usually smaller in size than the grains of brown tourmaline.

The blue tourmaline is free from inclusions as in the case of that described by Travis and Greenwood (4) in the Wirral Trias. The brown, however, is often crowded with inclusions, of which the most common are glass and iron-ore, while small crystals of rutile and zircon were also noted.

The brown tourmaline is common and frequently abundant, the pinkish is frequent, whilst the blue, though almost always present, is only represented, in each separation, by a few grains.

Brookite.—Only two or three grains are present in a few samples of sand that have been examined. The grains are usually well rounded and show marked striations. They are pale yellow in colour and sometimes very faintly pleochroic. A very imperfect cleavage was noted in one or two grains parallel to the direction of striation. The nature of the grains is readily determined from the interference figure, the crossing of the optic-axial planes for red and blue light usually being very clearly shown.

Staurolite.—This mineral, though almost invariably present, is never abundant, a few grains only being obtained as a rule from each separation. It occurs in pale yellow or reddish grains, sometimes showing slight pleochroism and a very characteristic toothed outline, due to fraying along the 110 cleavage, as described by Bosworth (5) in connection with the staurolite from the Keuper Marls around Charnwood. The grains average about ·1 mm. in diameter, though in the sandstones rich in garnets from Dundonald they measure as much as ·4 mm.

Micas.—Both muscovite and biotite are present, the former invariably. Muscovite, occurring generally in perfectly oval flakes, forms one of the principal heavy minerals in some of the flaggy sandstone. Biotite is less frequently present.

Chlorite is sometimes represented, especially in the finer sandstones, but is rarely abundant.

Hornblende.—This mineral is very rare, but was found in slight amount in the sandstones from Co. Londonderry, while one grain was detected in the sandstone from Red Ford, near Dungannon, Co. Tyrone. It occurs in small compact grains showing a tendency to prismatic habit due to breaking along the 110 cleavage. It is strongly coloured and shows marked pleochroism from yellowish green to bluish green. The extinction angle varies from 2° to 8° and a convergent light picture can always be obtained, with an optic axis emerging near the margin of the field. One or two green grains have been noted in the samples from Skegoniel and Falls Road, Belfast. They show the prismatic form of hornblende, but exhibit aggregate polarization and are possibly due to the decomposition of original hornblende.

Felspar.—Orthoclase is the most common variety. It occurs in rounded and angular grains and is always more or less kaolinized.

Microcline is always present and is most abundant in the Roe valley. It is usually fresher than the orthoclase.

Grains of plagioclase were occasionally seen, which gave extinction angles indicating albite and oligoclase as the species present.

An Authigenic Mineral.—The discovery of this mineral in the sandstone from Benbradagh was rather fortuitous, since it is normally lost with the fine rock powder in washing the sand before separation in bromoform. It is most easily separated from the rock by crumbling the sandstone over a watch glass, until the glass is covered with a thin layer of sand. If the glass is then tilted and all the sand allowed to fall off, a fine powder remains, which, on microscopic examination proves to consist of prefectly developed crystals resembling dolomite in form and cleavage and averaging ·05 mm. in diameter.

This mineral is insoluble in strong acid (except hydrofluoric) even after prolonged boiling, and microchemical tests show it to be an aluminium silicate probably with potash. The average refractive index is 1·52 and the double refraction is low. The extinction varies on different faces, it is either straight with the diagonals or makes a low angle with a crystal edge. The fast ray, in the former case, vibrates parallel to the short diagonal. Possibly the crystals have a slight tendency to be tabular, for in every case when a convergent light picture has been obtained the same result is found. This face is approximately normal, either to an obtuse bisectrix or an optic normal, since the hyperbola leave the field of the microscope rapidly. Serious difficulties are encountered in determining the specific gravity of so small a mineral and an accurate figure cannot yet be given, although it is thought to be roughly equal to that for orthoclase.

Lath-shaped forms have also been noted, which show straight extinction with their length, the vibration direction of the slow ray.

The Benbradagh sandstone is very friable and had to be specially treated before a thin section could be made. It is a fine-grained rock composed of angular and subangular grains of quartz with a little orthoclase, microcline, and oligoclase and occasional flakes of biotite and muscovite. Each grain is surrounded by a pellicle of hematite. The rhomb-shaped crystals cannot be seen over the greater part of the slide, but towards the edge, where the rock has been almost rubbed away, they occur abundantly.

The mineral is evidently authigenic and its properties indicate a felspar (possibly orthoclase), but this requires confirmation and further investigations are being made.

C. *Distribution of the Minerals.*

1. *The heavy minerals.*—Examination of material collected from successive layers in various localities shows that variation in the relative abundance of the heavy minerals takes place from layer to layer and may be correlated with the coarseness of the sandstone. Garnet and, to a lesser degree, staurolite are more abundant in the coarser sands, whilst zircon, rutile, and apatite predominate in the fine. Consequently great variation in the relative abundance of the heavy minerals is sometimes found within a few feet. In view of this, the tabular summary of the distribution of heavy minerals was compiled to show the average abundance of each species, at the various localities, as determined from a number of samples.

TABLE I.—TABULAR SUMMARY OF THE DISTRIBUTION OF HEAVY MINERALS.

8 = superabundant ; 7 = very abundant ; 6 = abundant ; 5 = common ;
4 = frequent ; 3 = scarce ; 2 = rare ; 1 = very rare.

	Locality.	Garnet.	Anatase.	Rutile.	Zircon.	Apatite.	Ilmenite and Leucoxene.	Tourmaline.	Staurolite.	Brookite.	Hornblende.
Co. Antrim.	1.[1] Milltown	6	—	6	6	—	6	6	3	—	—
	2. Falls Road	6	4	3	4	5	6	6	1	1	1(?)
	3. Fortwilliam Park	1	1	5	7	4	6	6	1	1	—
	4. Skegoniel	5	1	5	6	4	5	7	3	—	—
	5. White Abbey	6	—	4	7	—	4	5	2	—	—
Co. Down.	6. Marino	6	3	5	6	—	7	5	3	—	—
	7. Dundonald. Stream near railway station	8	—	2	2	1	1	7	6	—	—
	8. Dundonald. West of Dunlady House	2	5	3	3	5	7	2	—	—	—
	9. "Redstone" quarry	—	—	6	6	—	8	—	—	—	—
	10. Scrabo Hill	1	3	4	4	3	8	1	—	—	—
	11. Scrabo railway cutting	6	—	4	3	3	8	5	—	—	—
	12. Ards Peninsula	1	4	4	6	6	6	8	2	—	—
Co. Tyrone.	13. Red Ford	1	2	4	7	—	7	4	1	—	1
	14. Coalisland	1	3	4	7	—	7	6	—	—	1
Co. Londonderry.	15. Near Maple Lodge	6	—	3	4	—	6	4	2	—	—
	16. Boherboy Cottage	6	3	5	6	—	7	4	1	1	—
	17. Benbradagh	2	—	3	5	—	7	5	—	—	1
	18. Donald's Hill	8	1	3	3	4	5	4	—	—	—
	19. Near Drumagosker	4	1	3	5	—	7	1	2	—	1
	20. Stream from Kready mountain to Drummond Bridge	2	1	4	7	—	7	3	2	—	1
	21. Curly River	7	—	3	6	—	6	4	—	—	1
	22. Lyn-burn	6	1	3	3	4	6	3	1	—	—
Co. Antrim.	23. Murlough Bay	1	1	3	4	—	8	4	1	—	—
	24. Ballyeamon River	2	—	6	8	—	8	2	1	—	—
	25. Red Bay	6	—	2	3	—	7	3	2	—	—
	26. Glenariff	4	1	6	8	—	3	2	1	—	—
Border of Cos. Cavan & Meath.	Enniskeen River	5	2	4	4	5	6	6	1	1	—

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[1] The numbers are the same as those used on the map, Fig. 1, to indicate the localities from which material was collected.

NOTE.—Muscovite, chlorite, and magnetite are not shown in the table, although they are usually present. This is on account of the difficulty of estimating the amount of muscovite and chlorite present, since much of these minerals is lost whilst washing the sand. No estimate is given for magnetite on account of its solubility in HCl., although it is usually present and less abundant than ilmenite. The presence of apatite is only shown in the case of the pale sands which could be examined without preliminary boiling in HCl.

The table shows no regular lateral variation of heavy mineral content, even the blue and pinkish varieties of tourmaline, not shown separately in the table, are found in small amounts at all localities. Hornblende is the only mineral with a definite restricted occurrence. Although represented only by one or two grains in each sample, yet it is characteristic of the sandstone to the west of the plateau in Londonderry and Tyrone. The only grains recorded from the east are those from the Lagan Valley, which are decomposed and doubtful.

It should be mentioned, however, that whilst in general the heavy residue from one locality is indistinguishable from that of another, certain districts are characterized by bands rich in ilmenite with zircon, rutile, and apatite in subordinate amounts, almost and sometimes quite to the exclusion of other minerals. This is noticeably the case at Scrabo Hill. Samples were collected from all horizons in the excellent quarry exposures at Scrabo, yet not more than two or three grains of garnet and tourmaline and no staurolite have been found in the whole thickness of about 120 feet. Only at the extreme base in the railway cutting do garnet and tourmaline appear in any quantity and staurolite is still absent. The sandstone from " Redstone " quarry on the Belfast and Newtownards road to the north-west of Scrabo is exactly similar. Bands rich in ilmenite but never quite so deficient in other species, have been found in the higher beds at Red Bay, Benbradagh, and at Murlough Bay. It is noticeable that these bands, with the exception of Murlough Bay, where tourmaline and garnet are never entirely absent, come from the higher part of the series, yet such a composition is not characteristic of the higher horizons everywhere, as is seen from the samples examined from the Lagan Valley not far from the junction with the marl.

2. *The light minerals.*—Felspar is usually abundant. Rough estimates were made, by counting, of the percentage of felspar present in the light residue in various specimens from the Lagan and Dundonald valleys. It was found to form as much as 30% to 40% of the bulk of the rocks. In some of the sandstones from the Roe Valley it appeared to be so abundant that a special examination was made. A portion of the light residue of the sand from the stream flowing under Artikelly bridge was suspended in potassium-mercuric-iodide to separate quartz from felspar. As a result 51% of felspar, by weight, was found to be present. Not only is felspar more abundant in the Roe Valley, but the proportion of microcline to orthoclase increases, although orthoclase is always the more common.

III. Description of the Conglomerate and Pebble Beds.

Conglomerate and pebble beds are recorded in the Survey Memoirs as occurring at Murlough Bay (13), Red Bay–Cushendall (14), in the Roe Valley near Limavady (15), at Cookstown (16), and in the Dundonald Valley (17). The conglomerate and pebble beds of Murlough Bay, Red Bay, and the Roe and Dundonald Valleys were examined and rock fragments collected from them for identification, but the conglomerate beds at Cookstown could not be located. These conglomerate beds will now be briefly described together with the rock types represented in them.

1. *Murlough Bay.*

The small exposure of sandstone in Murlough Bay contains angular fragments of mica schist, pebbles of brown quartzite, vein quartz, and occasional gneiss pebbles. All of these have evidently been derived from the underlying Dalradian.

2. *Red Bay.*

The Triassic sandstone is well exposed in the cliffs skirting Red Bay, between Cushendall and Waterfoot. A coarse basal conglomerate appears near the coastguard station, Cushendall; fragments of schist are most abundant, varying in size from blocks measuring 1 foot or more across to small chips about 1 inch across. The schist fragments are arranged with their foliation planes parallel to the bedding planes of the red sandstone in which they are embedded. Pebbles of quartzite, vein quartz, gneiss, and rarely felstone porphyry are also present. About 40 feet from the arch quartzite becomes the predominant rock in the conglomerate, and occurs in well-rounded boulders measuring as much as 1½ feet in diameter. The matrix of the conglomerate is a hard dull red sandstone. Viewed from the cliff behind the quartzite conglomerate appears as a tumbled mass of boulders, bedding planes being no longer apparent. The higher horizons exposed in the cliff are pebble beds alternating with thin beds of sandstone. These pebble beds proved more interesting than the massive conglomerate. Angular fragments of mica schist predominate, but in addition pebbles of vein quartz, brown quartzite, pink felspar-porphyry, grey felspar-porphyry, and grey gneiss were collected. A pebble measuring about 4 to 5 inches in diameter of white quartzite containing pink felspars was also found. Pebbles of black schist become fairly common in the higher layers.

The more interesting of these pebbles were sectioned for microscopic examination and are described below.

(*a*) *Pink Felspar-Porphyry.*—This rock is of a type easily recognized. In the pebbles large crystals of pink felspar measuring as much as ½ inch across and rounded quartz blebs can be seen surrounded by a fine pink ground-mass. When examined in section the most abundant phenocrysts are found to be oligoclase. Porphyritic crystals of orthoclase are scarce and rounded quartz crystals showing signs of corrosion are fairly common. Biotite is the only ferro-magnesian mineral in the section, though hornblende has been distinguished in the hand specimens. The oligoclase shows a marked zonal structure and is usually very fresh except for the development of a fine white mica along the junction of the zones. The ground mass is a microcrystalline aggregate of quartz and felspar.

(*b*) *Grey Felspar-Porphyry.*—The hand specimens show closely packed phenocrysts of white felspar averaging about $\frac{1}{10}$ inch across and occasional flakes of biotite in a compact grey groundmass. When examined microscopically this rock is found to be allied to the pink felspar-porphyry. The phenocrysts are again well-zoned oligoclase with white mica developed along the limit of the zones. A few idiomorphic crystals of orthoclase are present and the groundmass is a microcrystalline quartz-felspar aggregate.

(*c*) *Black Schist.*—On sectioning, the black schist was found to consist of fine angular quartz grains and very much kaolinized felspar, in a matrix of ilmenite and magnetite. The iron ores appeared to form rather more than half of the bulk of the rock. This was confirmed by pounding the rock to separate the individual grains and then separating in bromoform. The heavy residue of specific gravity greater than 2·9 was found to form more than half of the bulk of the rock and to consist of ilmenite and magnetite.

(*d*) *Grey Gneiss.*—This rock is closely related to the black schist, ilmenite being very abundant. It is coarser in grain than the schist and the quartz is crowded with inclusions. The inclusions are mainly of irregular quartz, elongated in the direction of schistocity, but in addition zircon, apatite, and garnets are frequent. The felspar is very much kaolinized.

(*e*) *Felspathic Quartzite.*—This is a coarse white quartzite with pink felspars and in places rounded opalescent grains of quartz. In section the felspar proves to be microcline which is usually slightly kaolinized. It occurs in rounded grains which average about 2·5 mm. in diameter. The microcline together with rounded grains of quartz is embedded in a microcrystalline groundmass. This matrix is mainly quartzose, but some microcline and a little oligoclase are present. The quartz grains have crenulate edges and exhibit strain shadows. They show the dot and hairlike type of inclusion.

3. *The Roe Valley.*

East of Limavady pebble beds are exposed in the Lyn-burn which flows under Artikelly bridge. At the marked bend in the stream south of the Coleraine road the section is follows :—

Boulder-clay.
Red sandstone.
Pebble bed, about 2 feet thick.
Red sandstone, about 4 feet thick.
Pebble bed forming bed of stream.

The pebbles rarely exceed 3 inches in length and are usually smaller. The rock types represented among the pebbles are in order of frequency:—brown, green and grey quartzite, pink and white gneiss, which is always very rotten, vein quartz, and rarely small pebbles of brown sandstone like the local Carboniferous, and of coarse grit or arkose in which pink felspar is abundant.

Some of these pebbles are described in more detail:—

(*a*) *Pink Gneiss.*—This rock has a granitic appearance in the hand specimen and a very noticeable foliation. Where it is most rotten in the bed of the stream it tends to crumble and break along the foliation planes. On sectioning, the rock was found to contain more or less rounded grains of microcline and quartz averaging about 1 mm. in diameter, in a microcrystalline matrix of quartz with a little microcline. In places the matrix becomes almost cryptocrystalline. The grains have crenulate margins and the larger ones have frequently broken down round their edges to a microcrystalline or cryptocrystalline aggregate.

(*b*) *Green Quartzite.*—This is a fine-grained quartzite or quartz schist with abundant ilmenite. As in the gneiss, microcline is characteristic. The other colours of quartzite were not sectioned, but small portions were pounded up and examined. As a result microcline was found to be present in every type.

(*c*) *Arkose.*—This rock closely resembles the Torridon sandstone. The pebbles shade from pink to grey and pink felspar is very evident. Some of the felspars measure as much as ·2 inch across. In section it is found to consist of well-rounded grains of quartz, microcline, and more rarely perthite and oligoclase. The grains average about 1 mm. in diameter. Many of the grains have finely crenulate edges and intercrystallization can be seen in places, giving a mosaic structure. Generally speaking, however, the grains are distinct and are separated from one another by a fine white mica. Microcline is strikingly abundant, distinctly more so than in the gneiss and quartzites previously described, and is exceedingly fresh. The relative abundance and high degree of rounding of the various heavy minerals present in the arkose, which are recorded in another part of this paper, also indicate that this is a distinct type and not a variety of the quartzites.

4. *Cookstown.*

As already mentioned, the conglomerate beds at Cookstown could not be located: this was possibly due to the flooding of the streams in which exposures occur. From the following description given by Egan (16), however, they appear to be local in character: " The lower portions are composed of a coarse sandy red breccia with some thin layers of sandstone, the former containing fragments of the underlying granite and schists, and a few quartz pebbles. Higher up they become finer and less compacted; and at the top they become quartzose and assume the form of a fine conglomerate with interstratified beds of sandstone."

5. *Dundonald Valley.*

In the pebble beds near Dundonald railway station, which are exposed in the small streams flowing into the Dundonald Valley, only angular chips of slate and pebbles of vein quartz are present. These have evidently been derived from the underlying Palaeozoic slate.

IV. THE SOURCE OF PEBBLES.

In connection with the Cushendall conglomerate beds the rocks exposed to the north of the area between Cushendun and Tornamoney were examined.

At Cushendun a red felspar-porphyry, which is intrusive in the Dalradians, is exposed in small quarries. This is the rock described by M. Henry (14*b*) as "quartziferous porphyry" and cited by Harker (6) as a good example of a quartz-monzonsite-porphyry. Sections of this rock proved to be identical with those of the red felspar-porphyry found in the pebble beds at Red Bay, the abundance of zoned oligoclase with fine mica delimiting the zones being unmistakable.

On the north side of Cushendun Bay several dykes of grey porphyry with abundant crystals of white felspar traverse the schists. Microscopic examination of this rock shows it to be closely allied to the red porphyry. The oligoclase phenocrysts have, however, undergone a curious type of decomposition and become entirely cryptocrystalline, so that they are no longer recognizable as felspar crystals. That oligoclase similar to that in the red felspar-porphyry was the original mineral is indicated by the presence of the white mica which still shows the concentric arrangement parallel to the edges of the crystal and so gives evidence of the original zonal character of the mineral. A few very fresh crystals of orthoclase are present and rounded, much corroded crystals of quartz. Biotite and chlorite are present in small amount. A fresher type of this dyke rock must have furnished the material for the grey felspar-porphyry pebbles in the conglomerate.

The silver mica schist which predominates in the Red Bay conglomerate beds is the normal type of schist exposed in the Dalradians of the Tor Head Series, whilst the grey gneiss can be matched in the same series. The quartzites are also derived from the Dalradians, although some of the boulders have doubtless been derived via the Old Red Conglomerate of Cushendun.

Although the black schist pebbles were not exactly matched in the Tor Head Series, yet it seems probable that this is a variety of the dark schists exposed to the north of Cushendun. These are hornblende biotite schists, with a considerable quantity of ilmenite and some iron pyrites present. Continued search would doubtless reveal a type similar to the iron ore schist pebble.

The most characteristic feature of the pebble beds near Limavady is the abundance of microcline in pebbles of all types, whether gneiss, quartzite, or arkose. In the case of the gneiss and quartzite pebbles the rounding of the larger grains which are enclosed by a matrix of secondary quartz is also characteristic. Both these features are shown by the Dalradian quartzites in Jura and Argyllshire. A comparison of slides of these quartzites, in the Geological Survey collection, with those made from quartzite and gneiss pebbles found in Lyn-burn and the felspathic quartzite from Cushendall brings out an exact similarity.

Unfortunately an examination of the Irish quartzites has not been possible. The quartzites from several localities in Ireland, however, are described in the Survey Memoirs as being felspathic (18) and at times grading into gneiss (19). In the petrographical notes on Inishowen (20) the quartzites of Ineuran Bay are described as "pink in colour and very fresh. In section under the miscroscope the original quartz grains are seen to have been mostly well rounded, some are subangular but the fragmental structure is still preserved. The rocks contain a large quantity of felspar which often shows microclinic or microperthitic structure. The form of the felspar is often remarkably well defined."

Thus the quartzite and gneiss pebbles are allied to the Dalradian quartzites both in structure and in the presence of microcline and were evidently derived from the quartzite ridge which extended from Argyllshire, through Jura to Donegal in Triassic times.

The arkose pebbles, as has already been shown, are very similar to the Torridon sandstone, except that in microscopic section they do not show the iron staining which is characteristic of the Torridonian and it is possible that they might be matched amongst the grit bands which occur in Donegal. Whether they originated in the Torridonian or the Dalradian Series, however, makes no difference to the direction from which they were derived. If Dalradian they originated, with the quartzites, in the ridge of metamorphic rocks which existed to the north and if Torridonian they were probably derived from a southerly extension of the Islay Torridon.

The pebble beds of other localities, as already stated, are quite evidently local in origin.

V. HEAVY MINERALS PRESENT IN THE PEBBLES.

Several examples of various types of pebbles found in the pebble beds were pounded up, separated in bromoform, and the heavy residue examined. The result of this examination, showing the minerals present and their relative abundance, is tabulated below:—

8 = superabundant ; 7 = very abundant ; 6 = abundant ; 5 = common ;
4 = frequent ; 3 = scarce ; 2 = rare ; 1 = very rare.

	Garnet.	Rutile.	Zircon.	Apatite.	Ilmenite and Leucoxene.	Magnetite.	Tourmaline.	Staurolite.	Chlorite.	Muscovite.
Schist—from Cushendall and Murlough Bay .	7	1	5	7	8	1	1	—	8	7
Black schist—Cushendall	—	—	4	4	8	6	—	—	—	—
Grey gneiss—Cushendall	5	1	5	7	3	8	3	1	4	—
Pink gneiss—near Limavady	3	2	5	5	8	4	1	—	—	—
Arkose—nr. Limavady .	6	3	5	7	4	8	3	—	—	—
Green quartzite—near Limavady	6	4	5	2	3	6	—	—	1	—
Brown quartzite — near Limavady	4	1	5	2	3	8	1	—	—	—
Felspathic quartzite—Cushendall	5	1	4	4	1	8	1	—	1	—
Brown quartzite—Cushendall	5	2	4	5	2	7	—	—	1	—
Slate—Dundonald .	6	5	6	4	7	6	3	—	5	—

The schist, gneiss, and quartzites were all found to contain a high percentage of heavy minerals, whilst the slate, although less rich in the amount of heavy minerals present, showed exactly the same species. The principal characteristics of the heavy minerals from the pebbles may be summarized as follows :—

Garnets occur in the pebbles of all types as small and medium sized grains which are either pink or colourless, the former predominating. They are frequently crowded with inclusions so that they do not always appear to be completely isotropic. In the pebbles of grey gneiss the small garnets show perfect dodecahedral form.

Rutile is not common in any of the pebbles except the slate, but when present it shows a rounded prismatic form and is reddish-brown in colour.

Zircon is common and occurs as well-formed crystals, resembling those recorded from the Triassic sandstone in form, and as oval grains. It frequently shows zonal structure and sometimes has a cloudy appearance. Purple zircon is present in the heavy residue from the arkose, schist, and green and brown quartzite pebbles. In the quartzites and arkose it is oval in shape, whilst in the schist pebbles, although usually oval, it sometimes shows good prismatic form.

Apatite is sometimes more abundant than zircon and usually shows prismatic form with rounded terminations, or else is terminated by the basal plane ; at other times it occurs as irregular grains. In the arkose the apatite is well rounded and frequently almost spherical.

Magnetite and Ilmenite are very abundant and occur usually in irregular grains. The ilmenite is fresh compared with that in the sandstone, though some leucoxene can be seen. In the arkose and the green quartzite both magnetite and ilmenite grains are well rounded and sometimes almost spherical.

Tourmaline is scarce in all the pebbles that have been examined. In the schist it occurs as well-formed brown or pinkish-brown prismatic crystals with the trigonal pyramid predominant at one end and the base at the other. In the grey gneiss irregular and rounded grains of brown and pinkish-brown tourmaline are present and in addition a few irregular grains of blue tourmaline have been seen, whilst grains of brown and green tourmaline are present in some of the quartzites and the arkose.

Staurolite does not appear in the heavy residues from any of the pebbles except the grey gneiss and in that case only one small grain was found.

VI. HEAVY MINERALS PRESENT IN NEIGHBOURING OLDER FORMATIONS.

In order to ascertain whether or not the neighbouring older sediments may have contributed to the Triassic sandstone, a few samples of Ordovician slate, Old Red sandstone, and Carboniferous sandstone were examined. The Carboniferous sandstone was collected from near Ballycastle and from the Roe Valley, the Old Red sandstone from between Cushendall and Cushendun, and the Ordovician slate from near Newtownbreda.

Each yielded the same suite of heavy minerals as the Triassic sandstone, with the exception of staurolite, which was not found in any of the heavy residues. Also the same type of quartz was found in each. The fact that staurolite was not found in the heavy residues cannot be taken to prove its absence from these formations. In the Triassic sandstone staurolite is a very rare mineral, only one or two grains being found in large quantities of sand, so that its non-appearance may be due to the small number of samples that have been examined.

The following table shows the average relative abundance of the various heavy minerals in the specimens examined, but should not be regarded in any case as typical of the whole formation.

8 = superabundant;
7 = very abundant;
6 = abundant;
5 = common;
4 = frequent;
3 = scarce;
2 = rare;
1 = very rare;
x = present, but relative abundance not determined.

	Garnet.	Rutile.	Zircon.	Apatite.	Ilmenite and Leucoxene.	Magnetite.	Tourmaline.	Staurolite.	Chlorite.	Muscovite.
Ordovician slate . .	4	4	4	3	7	1	2	—	x	x
Old Red sandstone .	1	1	5	x	8	x	3	—	—	x
Carboniferous sandstone, from the Roe Valley .	2	5	7	2	6	x	2	—	—	x
Carboniferous sandstone, from Ballycastle .	4	5	8	x	7	x	3	—	—	x

VII. THE SOURCE OF THE HEAVY MINERALS IN THE SANDSTONE.

The derivation of the sandstone is clearly indicated by the assemblage of minerals present. It has already been shown that, according to the principles enunciated by Mackie (3), the quartz was derived from gneiss or schist, a conclusion which is upheld by the frequency of strain-shadows and schistose grains. The presence of the metamorphic mineral staurolite and the abundance of muscovite point in the same direction. This suggests that the local Dalradian series forms the most likely source of the material.

With the exception of staurolite, a mineral suite similar to that found in the sandstone was found to characterize the fragments of Dalradian schist, gneiss, and quartzite found in the pebble beds. Not only are the mineral suites similar, but each mineral species shows the same characteristics in the Dalradians as in the sandstone. Although staurolite was not found in the pebbles examined, yet it is certainly present in the local schists, since it was recorded by Geikie (13*b*) as occurring in the schists at Ballycastle. The only difficulty appears to be the relative abundance of tourmaline in the sandstone and its relative scarcity in the heavy residues from the pebbles examined. In spite of this, the fact that all the varieties of tourmaline found in the sandstone are present in the metamorphic rocks strongly suggests that they were derived from these rocks. Also tourmaline evidently becomes characteristic of the schists in certain localities, having been recorded by the Survey from near Ballycastle (13*b*) and the schistose ridge north-west of Maghera (21).

The neighbouring older sediments are also characterized by the same suite of heavy minerals as the Triassic sandstone and the same type of quartz, so that the question arises as to whether the greater part of the material was derived directly from the Dalradian Series or indirectly via the older sediments. Near Limavady fragments of the local Carboniferous sandstone in the pebble beds clearly indicate that this formation was providing some material. Similarly in the neighbourhood of Cushendall the underlying Old Red Sandstone contributed at least to the basement beds. In the south the Ordovician and Silurian were yielding material, as shown by the presence of slate fragments in the small conglomerate beds in the Dundonald Valley.

In the north of the area there can be little doubt that the main part of the sandstone was derived directly from the metamorphic rocks. The percentage of felspar is there so high as to make it seem unlikely that it can have been derived from pre-existing sediments, whilst the fact that microcline is most abundant in the north indicates that it was there derived directly from the quartzites and gneiss. That these rocks played an important part in providing material even in the south of the area is rather suggested by the fact that the Triassic sandstone is richer in the percentage of heavy minerals present than the neighbouring older sediments. This implies a general drift of material from north to south, a view which is upheld by the greater abundance of felspar and particularly microcline in the Roe valley as compared with the south and the presence of fresh hornblende in Cos. Londonderry and Tyrone with an absence of fresh hornblende in the south. Additional strength is perhaps given to the idea of a flow from north to south by the degree of rounding of the quartz grains. In the northern localities they vary from angular to subangular, whilst in the south a larger percentage are subrounded to rounded. This is capable, however, of other interpretation.

A record was kept of the direction of current-bedding observed in various localities, in the hope of learning something definite as to the direction of drift of the material, but it was found to be of little value, since the directions are very variable, though the balance of evidence is in favour of flow along the Dundonald Valley in the direction of Strangford Lough.

VIII. THE GEOGRAPHY OF NORTH-EAST IRELAND IN TRIASSIC SANDSTONE TIMES AND THE MODE OF ACCUMULATION OF THE MATERIAL.

From the evidence of the conglomerate beds, it is apparent that, in Triassic sandstone times, the rocks of the Tor Head Series formed part of a ridge from which material was carried both to the north and the south. Further evidence of this ridge is to be found in the thinning of the sandstone. The sandstone reaches its greatest development in the Lagan Valley, where bores in Belfast and near Lisburn have revealed a thickness exceeding 500 feet, whilst in the neighbourhood of Carrickfergus the thickness has been estimated by Doyle as between 800 and 1,000 feet. The estimate given by M. Henry of the combined thickness of the sandstone and marl near Cushendall, however, is only 700 feet; moreover, at the head of the Ballyeamon Valley the Trias overlaps the Old Red Sandstone and thins out. North of the ridge in Murlough Bay and on the north-east slope of Carnamore Mt. the Geological Survey give the total thickness of the sandstones and marls as only 60 feet. The outcrop

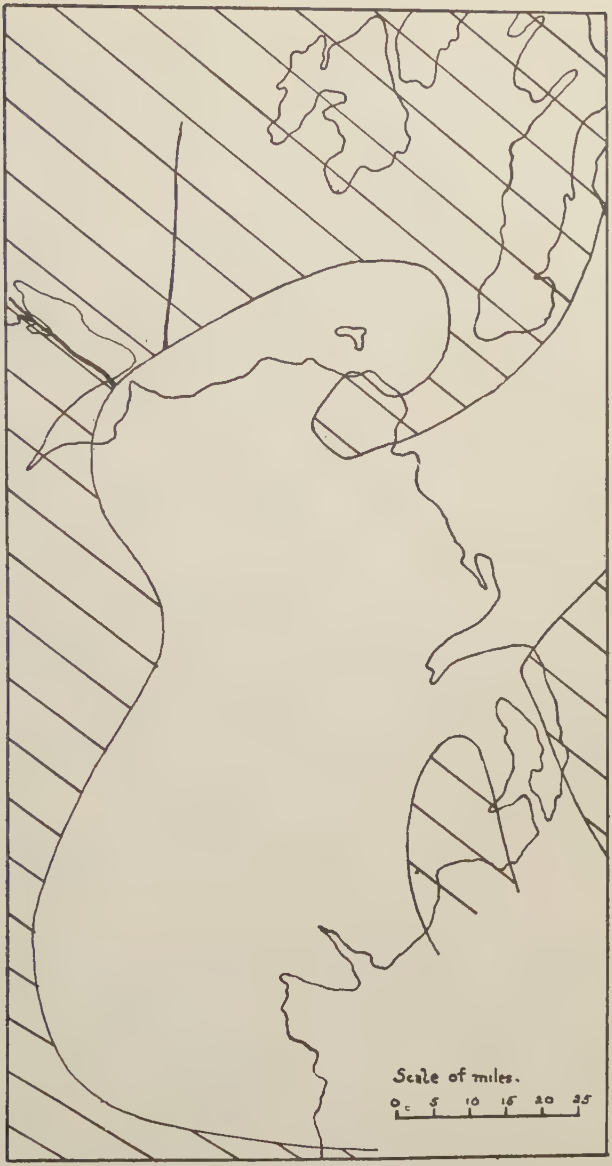

Fig. 2.—Map showing the physical geography of N.E. Ireland in early Triassic times.
The unshaded portion represents the basin of deposition.

of sandstone in Bush River, about 10 miles west of Cushendall, probably marks the western termination of this ridge, which may have been continuous with the rocks of Kintyre.

According to Jukes-Browne (7), a landmass extended across from Scandinavia, through Scotland to the north-west of Ireland and probably far into the area of the north Atlantic. The southern part of this landmass, where it adjoined the Irish Triassic deposits, was formed by the Dalradian Series of schist, quartzite, and gneiss which extended across from Scotland to Ireland. It is from this elevated area that the main part of the Irish Triassic sandstone must have been derived. In view of the occurrence of pebbles resembling the Torridon sandstone and Dalradian quartzites in the pebble beds near Limavady it is probable that a river entered the area of deposition from the north. This river need not have been either long or powerful, for the metamorphic rocks are close at hand, whilst Torridon sandstone occurs in Islay, and a slight extension of this outcrop to the south-west would bring it very close to the pebble beds. Also these pebble beds are small in extent and the number of pebbles is not very large, since they are scattered at intervals through sandstone rather than forming a massive conglomerate.

It seems likely that the sandstone never extended much farther westward than its present boundary, for the rocks of the Slieve Gallion district provided material for the conglomerate beds of Cookstown to the south-east. Very little information can be gained as to the original southerly extension of the sandstone. That deposition took place far to the south of the Lagan Valley is known from the occurrence of the isolated outlier of sandstone and marl near Kingscourt. From the presence of chips of slate in the sandstone of the Dundonald Valley, however, it may be inferred that such rocks were exposed close at hand, so that part of the Ordovician and Silurian slates must have risen above the level of deposition, at least in early sandstone times, and the Trias of the Dundonald Valley was accumulated in an old depression in the Palaeozoic rocks.

An examination of the degree of rounding of the quartz grains leads to the conclusion that whereas water played the greater part in the deposition of the sand in the north, wind action was more prevalent in the south. The sandstone bounding the metamorphic rocks is composed for the most part of subangular and angular grains, though some of the coarse sandstone which forms the matrix of the massive conglomerates of Cushendall contains a fair percentage of grains which are subrounded to rounded. In the Lagan Valley rounding is more common and some of the beds may be largely composed of wind-blown sand. Yet even there beds composed of subangular and angular grains are not wanting.

Current-bedding is particularly characteristic in the south, the best examples being found at Scrabo Hill and at Milltown near Derriaghy, though it also occurs in the north at Waterfoot (near Cushendall) and near Dungiven. The current-bedding is of the irregular type described by Grabau (8) as characteristic of Eolian deposits, and the exampes figured by him can easily be matched in the Irish Triassic sandstone. The bedding is characterized by variation in the angle and direction of slope of the laminae in the same stratum or successive strata and by lack of parallelism of the dividing laminae.

Clay galls are characteristic of much of the sandstone in the Lagan Valley and are best developed at Scrabo Hill and in sections seen in Falls Road, Belfast. According to Grabau (9) clay galls may " be regarded as practically positive evidence of a subaerial origin of the rock containing them ". He regards them as being formed from thin mud layers which, when exposed to the heat of the sun, become dry and curl up into masses resembling shavings. When dry these shavings may be blown into neighbouring sand-dunes where they are buried. During the rainy seasons when the dune is saturated with water the clay shavings are softened and become compressed into clay pellets. In support of this view I have found that the clay galls are frequently associated with the best rounded sands.

Thus it appears that a basin of deposition extended over north-east Ireland in Triassic sandstones times, and probably reached its greatest depth in the region of what is now the Lagan Valley. Possibly a river entered this basin from the north and small streams drained the surrounding Pre-Cambrian and Palaeozoic highlands at least in times of heavy rainfall. These streams spread out their debris over the basin floor. In early Triassic times boulders and pebbles were washed down the slopes of the surrounding highlands, particularly from the north, where the land reached its greatest elevation. As the heights were progressively lowered the streams moved smaller and smaller fragments, until finally, they were only capable of carrying sand.

Deposition may have been intermittent, taking place mainly during periods of heavy rainfall. The thin beds of sandstone, intercalated in the conglomerates, which usually vary from a few inches to a foot in thickness, possibly represent the drier periods.

Towards the south wind action was more prevalent and the sand was blown over the basin floor and in places piled up into dunes. At times, probably after periods of greater rainfall, pools must have collected over the lower southern part of the basin and in these pools the thin marl bands which can be found intercalated in the sandstone were formed, or thin marl layers which provided material for clay galls collected. Ripple marks were formed in the shallow water and on the drying of the pools sun cracks and rain prints developed. Into these same pools the more angular sands may have been washed directly by the streams.

In connection with the river claimed by Professor Bonney (10) as having carried pebbles from Scotland to the English midlands in Bunter times, it should be mentioned that no evidence of such a river exists in Ireland. Although there may have been a southerly drift of the finer material in Ireland, there was no transportation of pebbles from the north to the southern localities, so that if such a river existed its course must have lain to the east of Ireland.

IX. THE CORRELATION OF THE SANDSTONE.

The Geological Survey correlated the Irish Triassic sandstone with the complete development in Lancashire and Cheshire. They recognized the following horizons :—

Lower Keuper sandstone.
Upper Mottled sandstone.
Middle Bunter sandstone (Pebble beds).

In the Lagan and Dundonald Valleys where the sandstone shows its greatest thickness it was at first assigned to the Upper Mottled sandstone. Exception to this classification was made in the case of the sandstone of Scrabo Hill (17*b*) and that round Dundonald railway station (17*c*), where, in each locality, it is protected by a sill of dolerite. Here correlation with the Lower Keuper sandstone was made. The sandstone of other isolated exposures was also correlated with the Lower Keuper, namely, the small outcrop on the south-east shore of Belfast Lough, about 1 mile north-east of Holywood (17*d*) ; the beds exposed near Falls Road Cemetery, Belfast (22*a*) ; in a quarry about 2 miles north-west of Lisburn (22*b*) ; and at the base of the marls north-east of Hullstown (22*b*).

In 1904 Lamplugh (26) noted that " to the west of the Lagan the Keuper Marls rest directly upon soft sandy beds presenting the lithological characters of the Bunter Sandstone without the intervention of beds like those of Scrabo Hill " which are regarded as Keuper in age. He suggested the correlation of the Triassic sandstone of the Lagan Valley with that of Cumberland and the Isle of Man, rather than with the more distant area of Lancashire and Cheshire, and pointed out that " if this course be followed, the Trisasic sandstones of this part of Ireland may be regarded as the equivalent of the St. Bees' Sandstone, underlain as in Cumberland by the Lower Marls and with an attenuated representative of the Permian, comparable to that at Whitehaven and in the Isle of Man, occurring in places at their base." The presence of the Lower Marl was proved in various borings in Belfast.

An examination of the classification over the rest of north-east Ireland brings out the curious fact that all the northern sandstone, viz. that which outcrops in the neighbourhood of Cushendall (14*c*) and Murlough Bay (13*a*) in Co. Antrim and that outcropping to the west of the plateau in the Roe Valley (15*b*) has been classed as Lower Keuper, whilst the southern sandstone exposed in the Lagan and

Dundonald Valleys and in Counties Armagh, Tyrone, and Londonderry as far north as Magherafelt, was, with the exception of that of a few isolated exposures, classed as Bunter. All the Bunter was regarded as Upper Mottled sandstone with the exception of the conglomerate beds ot Cookstown, which were classed as Middle Bunter Pebble beds (16). Yet in both the north and the south of the area the sandstone passes up gradually into the overlying Keuper marls, so that this classification seems unnatural.

The lithological characters of the sandstone, with the exception of that of Scrabo Hill, are everywhere similar. Usually it is bright red in colour with the occasional intercalation of buff-coloured beds, and it varies from a fairly compact sandstone to a friable sand. Current-bedding and clay galls are common. At Scrabo Hill the sandstone is more compact and harder and is quarried for building stone. This greater hardness is probably due to the intrusion of the dykes and sills of dolerite with which the rock is here riddled. The sandstone of Scrabo Hill is also more variegated in colour, varying from the usual bright red and buff to dull red, purple, and green, and shows excellently current-bedding, ripple marks, sun cracks, rain prints, and clay galls. Thin beds of green or chocolate-coloured marl are intercalated here and there. At the base of the hill, in the railway cutting, the usual bright red and more friable type of sandstone again appears.

Nowhere in Ireland, with the exception of Scrabo Hill, can any change in the lithological characters be found in the sandstone as it passes to higher horizons, nor can any break be seen in the sequence, apart from insignificant local pebble beds, which would give evidence of a lower Bunter and upper Keuper member.

It has been pointed out by Sherlock (11), in the case of the Belfast area, that since the rock salt of Carrickfergus may be correlated with the Cheshire salt, the marl is evidently the Keuper marl and the underlying beds may represent both Bunter and Keuper sandstone. This might equally well be said of the sandstone throughout the Lagan Valley.

Similarly the sandstone of the northern localities which has been classed as Keuper, may also have some Bunter component. Since the sandstone is here thinner and nothing representing the Magnesian Limestone has been recorded, however, it is possible that deposition did not take place in the north at quite so early a date as in the southern basin round Belfast.

It was shown by Travis and Greenwood (12) in the case of the Triassic sandstone of Wirral that although the Bunter and Keuper are alike in the mineral assemblage present, yet they differ as to the physical condition of their component grains. The Bunter there shows a regularity of grain size and a high percentage of rounded grains, whist the Keuper is composed of an agglomerate of grains of widely different dimensions, a large percentage of which are angular and subangular. The Keuper is also characterized by the occurrence of large grains of felspar in quantity in the lower beds and by a greater average size of grain.

In view of this a careful watch has been kept for any change in the physical condition of the grains in examining samples from different horizons in Ireland. It has not, however, been found possible to distinguish between sandstone of Bunter and Keuper age in this way. The only generalization that can be made with regard to the physical conditions of the grains is that the sandstone of the northern outcrops is characteristically more angular than that of the southern, but this feature is to be attributed rather to nearness to the source of the material and the greater part played by water in its deposition than to difference in age.

With regard to the distinction made by the Survey between Bunter and Keuper at Scrabo Hill, mineralogical investigation shows that the upper part of the " Bunter " sandstone shown at the base of the quarries, although so different lithologically from the " Keuper ", is indistinguishable from it mineralogically, being characterized by the superabundance of ilmenite with zircon and apatite and an almost complete absence of other heavy minerals. The sandstone at the extreme base of the hill and exposed in the railway cutting, however, although identical lithologically with that exposed at the base of the quarries, shows the complete assemblage of heavy minerals characteristic of the normal sandstone. Also, the sandstone exposed in Red Stone quarry on the Belfast and Newtownards Road, classed by the Survey as Bunter, is identical with the Scrabo Keuper mineralogically. Hence, it seems that change of lithological character, such as colour change or greater hardness or compactness, does not necessarily indicate change of physical conditions at the time of deposition.

Stated briefly, the Triassic sandstone in Ireland forms one continuous series in which no lithological or mineralogical change (which may be regarded as anything but local in character) can be found in tracing the beds from their base to the junction with the marls.

In conclusion the writer would like to express her thanks to Professor P. G. Boswell and Professor J. K. Charlesworth for suggestions in the early stages of the research, to Dr. L. Hawkes for kindly reading and criticising the manuscript and to H.M. Geological Survey for allowing certain of the slides in their possession to be used for comparison with those made from some of the Irish pebbles.

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MEMOIRS OF THE GEOLOGICAL SURVEY OF IRELAND.

(13) Explanation of Sheets 7 and 8, 1888, (*a*) p. 17 ; (*b*) p. 11.
(14) Explanation of Sheet 14, 1886, (*a*) p. 14 ; (*b*) p. 26 ; (*c*) p. 11.
(15) Explanation of Sheet 12, 1885, (*a*) p. 15 ; (*b*) p. 14.
(16) Explanation of Sheet 27, 1881, p. 25.
(17) Explanation of Sheets 37 and 38 and part of 29, 1871, (*a*) pp. 38 and 39 ; (*b*) p. 12 ; (*c*) pp. 13 and 39 ; (*d*) p. 19.
(18) Explanation of Sheets 3, 4, 5, 9, 10, 11, 15, and 16, 1891, p. 158.
(19) Explanation of Sheet 25, 1887, p. 9.
(20) Explanation of Sheets 1, 2, 5, 6, and 11, 1890, p. 51.
(21) Explanation of Sheet 19, 1882, p. 13.
(22) Explanation of Sheet 36, 1871, (*a*) p. 23 ; (*b*) p. 26.
(23) Explanation of Sheets 21, 28, and 29, 1876, p. 9.
(24) Explanation of Sheet 35, 1877, p. 67.
(25) Explanation of Sheet 46, 1887, p. 8.
(26) Memoir on the Country around Belfast, 1904, p. 20.

REVIEWS.

LES PLATEAUX DU JURA CENTRAL : ÉTUDE MORPHOGÉNIQUE. By GEORGES CHABOT. Publications de la Faculté des Lettres de l'Université de Strasbourg, Fascicule 41. Paris : Les Belles Lettres ; Great Britain : Humphrey Milford, 1927. pp. 350, 85 text-figures, 4 plates. Price in Great Britain, 12*s*. 6*d*. net.

THIS is a detailed geomorphological study of the plateau region of the Central Jura, in which an attempt is made to trace the evolution of the present plateaux. Briefly, the author's conclusion is that the plateaux are the remains of a single peneplain which after its formation was broken up by faulting. The erosion which has taken place since the dislocation of the original peneplain is also dealt with in detail, and there is an interesting section on karst phenomena.

The work is very thorough. The views of previous writers are fully discussed, and there is an excellent bibliography. It is a very useful volume.

The book is printed on paper which is free from loading and is accordingly exceptionally light for its size. The views in the text and most of the sections have been drawn to suit the paper, but in some of the maps and sections the lines are too fine for the rough surface, and there is some loss of clearness. Plate I is a relief map of part of the area, and the other plates are photographic views.

P. L.

OEUVRES GÉOLOGIQUES DE MARCEL BERTRAND. Edited by EMM. DE MARGERIE, and published under the auspices of the Académie des Sciences. Vol. I. pp. xxii 708, + 184 text-figures, 12 plates, and a frontispiece in heliogravure. Paris : Dunod, 1927.

THE death of Marcel Bertrand in 1907 deprived geology, and especially tectonic geology, of one of its most brilliant investigators. He was extraordinarily original and fertile in ideas, and remarkably clear and logical in expounding them. But his fertility had one disadvantage. He was so much occupied in developing his conceptions that he never had time to combine them, and they still lie scattered in the journals in which they originally appeared. Many of his papers, however, have had a profound influence upon geological thought, and in 1922 the International Geological Congress expressed a hope that they might be republished in book form. It is in response to this expression of feeling that the Académie des Sciences undertook the work.

The number of articles and memoirs collected for the purpose is 163. All the publications that bear the name of Marcel Bertrand are to be reproduced, except the sheets of the *Carte géologique détaillée de la France* on the scale of 1 : 80,000 and two long memoirs already published by the Académie (*Mémoires présentés par divers savants à l'Académie des Sciences*, xxx, 2, 1889, and l, 2, 1908). The first of these is a study of the Mesozoic and Tertiary rocks of Granada and Malaga, and the second is a more general memoir on the folding of the earth's crust and the rôle of horizontal displacements.

Three volumes have been found necessary to contain the rest of Marcel Bertrand's work, and the preparation for publication has been entrusted to M. de Margerie. The extent and accuracy of M. de Margerie's knowledge and—perhaps even more—his sympathy make him an ideal editor in such a case.

The various articles and memoirs have been grouped according to subject and the first volume includes those dealing with the Jura and with Provence. As an introduction there is a summary of Bertrand's scientific work up to 1894, written by himself. The volume is beautifully produced. There are many figures in the text, and the maps and the longer sections are reproduced as plates, which are mounted so as to open out clear of the text. Three of the maps and three of the plates of sections are in colour. The frontispiece is a photograph of Marcel Bertrand reproduced in heliogravure. P. L.

WELLS AND SPRINGS OF WARWICKSHIRE. By L. RICHARDSON. Mem. Geol. Survey. pp. vi + 204, with 5 figures. Price 5*s*.

THE county of Warwick is not on the whole very well provided with underground water, and as is well known to all geologists, most of the Birmingham supply is derived from a distant source in central Wales, while Nuneaton gets a supply by arrangement with the Corporation of Leicester. This memoir contains an account, arranged on the usual plan, of the underground water resources actually derived from the county itself, giving a large amount of detail. There is an interesting description of the medicinal waters of Leamington, which are derived from the Keuper sandstones, and are therefore naturally somewhat saline. The water of the Pump Room is said to be radioactive. There are a fair number of deep borings in the county, made in search of water, many of which are very fully described. All these water memoirs are valuable sources of information for stratigraphical purposes, owing to their good accounts of well-sections and borings.

INTRODUCTION TO SCIENTIFIC STUDY OF THE SOIL. By N. M. COMBER. Arnold and Co.

PROFESSOR COMBER has produced in his *Introduction to the Scientific Study of the Soil* an elementary text-book which presents the most recent views on soil science. The work of Hissink, Oden, Robinson, Keen, and the author himself, has profoundly affected the whole trend of recent work on soil problems. Professor Comber is the first author to produce a readable and concise account of the present-day views on the subject in a form suitable for students. Soil science should be based on pure geology, and Professor Comber's book shows very well the application of soil physics and chemistry to the data supplied by geologists. It may fairly be considered that the trend of soil research in the future will follow pure geology and mineralogy to a much greater extent than was the case a few years ago. The book may be safely recommended to students of agricultural science and will provide information useful to field geologists interested in applied work.

L. F. N.

EVOLUTION AND CLASSIFICATION OF SOILS. By E. RAMANN. Translated by C. L. Whittles. Heffer and Sons.

THE work of Dr. E. Ramann exercised a profound effect on agricultural soil science and geology. The publication of his small work, *The Evolution and Classification of Soils*, translated by Dr. C. L. Whittles, is of great value in placing one of the classics of soil science within the reach of the student; and Messrs. Heffer and Sons, of Cambridge, have shown great enterprise in issuing the work at a price which makes it available for everyone. Dr. Whittles' translation is quite adequate, and he has preserved the spirit of Ramann's original work in a marked degree. The translation was made some years ago, and the introduction and footnotes were obviously written at the same time. The explanatory notes and introduction would have gained in value had they been brought up to date at the time of publication in view of the recent advances on methods of soil classification and examination. With the exception of one or two misprints the book has been well produced.

L. F. N.

PRINCIPLES OF SOIL MICROBIOLOGY. By S. A. WAKSMAN. Bailliere, Tindall and Cox.

RECENT work on the flora and fauna of the soil has led to the production of a large number of papers published in various journals in this and other countries, and Professor Waksman may be congratulated on the success which has attended his attempt to collect the scattered literature into one volume of reasonable size.

The author deals almost entirely with the changes in the organic content of the soil due to the activity of the micro-flora, and the book contains little of interest to the geologist. The debatable question of rock-weathering by bacteria only occupies some twenty-three pages of the volume. The author has dealt with that subject in a very interesting way, and most of the information at present available is included in the one chapter. It is, however, too brief to do justice to the importance of the theories of biological rock-weathering. The volume contains a full index of authors and a general bibliography of book literature. Recent publications are quoted in copious footnotes, and the only criticism that can be made of Professor Waksman's book is that a general bibliography of papers is not given as a separate section.

L. F. N.

REPORT OF THE COMMISSION ON PLIOCENE AND PLEISTOCENE TERRACES, edited by K. S. SANDFORD. Union Géographique Internationale, pp. 123, 1928.

AS will be seen from its title this publication appeals to geologists as well as to geographers. In point of fact it contains so much valuable matter in a condensed form that it cannot be reviewed in the ordinary way. The only possible course seems to be to give a list of the contents, for the information of geologists who may desire to read the papers for themselves.

The following are the titles of papers, some of which are abstracts only :—

1. Raised Beaches and Terraces of Egypt. By W. F. Hume and O. H. Little.
2. Changes of Level on the Palestine Coast. By Sir W. M. Flinders Petrie.
3. Terraces of the Nile in Upper Egypt. By K. S. Sandford and W. J. Arkell.
4. Les terrasses marines de la Grèce. By Ph. Negris.
5. Relazione sui Terrazzi fluviali e marini d'Italia. By M. Gortani.
6. Der Monte Argentario in Toskana. By G. Braun.
7. Les Terrasses fluviales de l'Espagne. By E. Hernández-Pacheco.
8. Les Zones d'Abrasion maritime ou lacustre de l'Èbre moyen. By L. Garcia-Sáinz.
9. Les Terrasses des Regions atlantiques françaises. By E. Chaput.
10. Evidences of Change of relative level between Land and Sea in Southern England since the Pliocene Period. By H. Dewey.
11. Raised Beaches of the British Isles. By W. B. Wright.
12. On the Climatic Equivalent of Raised Beach Mollusca. By D. Baden-Powell.
13. Land Oscillations in England at the close of the Neolithic depression. By C. J. Gilbert.
14. Post-Pliocene Movements in the Vicinity of Cambridge. By J. E. Marr.
15. Raised Beach Levels, Ayrshire Coast, from Ardrossan to Girvan. By V. A. Eyles.
16. A Raised Beach on the Outer Hebrides. By J. W. Gregory.
17. Les Terrasses alluviales de deux grands Fleuves asiatiques ; l'Euphrate et le Mékong. By C. Depéret.
18. Pleistocene Movements in Sierra Leone. By F. Dixey.
19. An Examination of the Tertiary and Quaternary Changes of Sea-level in South Africa, with special stress on the evidence in favour of a Recent World-wide Sinking of Ocean Level. By A. V. Krige.

THE IKUNO-AKENOBE METALLOGENETIC PROVINCE. By T. KATO. Japanese Journal of Geology and Geography, vol. v, 1927, p. 121.

IN this paper Professor Kato describes the geology of the Ikuno mining area, and to some extent revises his former work on Akenobe. The chief points of interest are that he has established the existence of the normal sequence of mineralization, viz. tin, tungsten, copper, zinc, and then gold in quartz. The country rock is largely rhyolite and andesite of Tertiary age, these being cut by the veins. But the author clearly states his view that the real ore-bringer is a plutonic intrusion lying below at no great depth, and not exposed at the surface owing to the comparatively late date of the intrusion. This is important in connection with the supposed volcanic or hydrothermal origin of certain tin deposits elsewhere.

R. H. R.

TIN MINING. By C. G. MOOR. pp. xi + 171, with 14 figures. London: Sir Isaac Pitman and Sons, Ltd., 1928. Price 8*s*. 6*d*.

THIS little book is clearly intended mainly for those who wish to gain a knowledge of the practical side of tin mining. The sections dealing with geology are necessarily brief, but they appear to be accurate as far as they go. The author has apparently had a wide experience in various countries, and he gives some interesting details of different types of tin-mining, if indeed it is justifiable to apply the term mining to the commonest methods of winning this metal, such as ground-sluicing, gravel pumping, and the different types of dredging. Tin working in alluvial deposits is in reality the making of more or less complicated forms of mud pies. It is only lode-workings that are truly mines, and these yield only a fraction of the world's output, though they are likely to increase in relative importance as the alluvials become exhausted.

R. H. R.

CORRESPONDENCE.

THE MAGMATIC ORIGIN OF ORES.

Sir,—The interesting letter of Mr. H. C. Sargent published in our last issue creates a somewhat anomalous situation, because the author of the paper referred to in it is also the editor of this Magazine, and it seems rather irregular for the editor in his private capacity to write a letter to himself in his editorial capacity. But our readers will perhaps excuse this unusual proceeding.

It may be well to confess that the suggestion of a granite bathylith underlying the mineralized area of Derbyshire was put forward mainly in default of a better explanation. The presence of great quantities of fluorspar must be accounted for somehow, and according to the accepted canons of geology fluorine is associated with acid intrusions, whereas the only known igneous rocks of that area are decidedly basic. However, the facts disclosed by the data supplied in Mr. Sargent's letter do seem to afford a possible explanation of the presence of fluorspar in that area as the result of the differentiation of a magma rich in potash and silica, with granitic affinities, though far from being a granite magma in the ordinary sense. It is of course obvious that a lava-flow cannot account *directly* for the formation of minerals higher up in the rock-series, which are necessarily of much later date than the lava. It should be remembered that fluorspar is also found in quantity in the northern part of the Pennine area, where the only igneous rock that could be concerned in its formation is the Whin Sill. The publication of Mr. Sargent's detailed work will be awaited with interest: till this occurs further speculation on the subject may well be deferred.

R. H. Rastall.

THE SILURO-DEVONIAN JUNCTION IN ENGLAND.

Sir,—No apology is needed from Dr. Robertson for reopening this controversy; on the contrary, his paper in the August number of the Geological Magazine is a welcome indication of the progress towards general agreement. Reviewing the subject from still another angle, he has expressed agreement with the main conclusion put forward by de Dorlodot, Barrois, myself, and others, that the Ludlow Bone-bed or the equivalent horizon elsewhere is the most generally satisfactory base for the Devonian. Dr. Robertson mentions that he does not accept certain statements in my 1923 paper in this Magazine, and that he disagrees with certain of the reasons given for the selection of the Ludlow Bone-bed as the Devonian base. I think there are only two points of apparent disagreement. I showed that the Ludlow Bone-bed passes laterally when traced southwards from Shropshire into a bone-bed conglomerate below which there is an unconformity of varying importance. Although a break in the succession is a help in mapping, Dr. Robertson is undoubtedly right in arguing that the limit should be determined where the sequence is unbroken and the presence of an unconformity which is frequent at about the Ludlow Bone-bed horizon away from Shropshire is really no argument for the choice of this horizon as the base of the Devonian. Dr. Robertson is also justified in hinting that I have tended to overemphasize the absence of fish in pre-Bone-bed strata. Their absence is comparative rather than complete! So far as I can see, only one other point of disagreement remains, and that is not one vital to the general conclusion. I was puzzled, and still am, over the interpretation of the sequence in Central Wales—the Afon Sawdde sections and the Llandilo district. The Geological Survey's reading of the succession in the latter area is perfectly clear, but I do not think the possibility of contemporaneity between part of the Green Beds and the Tilestones further east is entirely eliminated. Mr. S. H. Straw's recent work, from the brief abstract available, seems to confirm the possibility. When working over the ground in 1920–1, I was unable to satisfy myself as to the position of the Devonian base in Central Wales and Mr. Straw is no doubt right in stating that my tentative suggestion placed it too low.

Evidently much work remains to be done before agreement is reached between workers in this particular area, and it is desirable that it should be perfectly clear that the main question of the fixation of the Siluro-Devonian boundary is not dependant thereon.

L. DUDLEY STAMP.

LONDON SCHOOL OF ECONOMICS, W.C. 2.
9th September, 1928.

To face p. 481.]